

## BA Excel Add-In User's Manual (Version 0.0.32)

### Contents

|          |  |          |
|----------|--|----------|
| <b>1</b> | <b>The BA Add-In Functions</b>                         | <b>3</b> |
| 1.1      | Linear Regression Functions . . . . .                  | 3        |
| 1.1.1    | LinearRegTrain . . . . .                               | 3        |
| 1.1.2    | LinearRegPredict . . . . .                             | 6        |
| 1.2      | Logistic Regression Functions . . . . .                | 8        |
| 1.2.1    | LogisticRegTrain . . . . .                             | 8        |
| 1.2.2    | LogisticRegPredict . . . . .                           | 12       |
| 1.3      | K-Nearest Neighbor Functions (Content-based) . . . . . | 15       |
| 1.3.1    | knn_in . . . . .                                       | 15       |
| 1.3.2    | knn_in_rmse . . . . .                                  | 17       |
| 1.3.3    | knn_out . . . . .                                      | 19       |
| 1.4      | K-Nearest Neighbor Functions (User-based) . . . . .    | 21       |
| 1.4.1    | knn_in_movie . . . . .                                 | 21       |
| 1.4.2    | knn_in_movie_rmse . . . . .                            | 23       |
| 1.5      | Other KNN Functions . . . . .                          | 24       |
| 1.5.1    | knn_dist . . . . .                                     | 24       |
| 1.5.2    | knn_nearest . . . . .                                  | 26       |
| 1.6      | BA_RMSE . . . . .                                      | 27       |
| 1.7      | Classification Functions . . . . .                     | 29       |
| 1.7.1    | confusionMatrix . . . . .                              | 29       |

|       |                                       |    |
|-------|---------------------------------------|----|
| 1.7.2 | ROC . . . . .                         | 31 |
| 1.7.3 | AUC . . . . .                         | 34 |
| 1.7.4 | ROC (with cost information) . . . . . | 34 |
| 1.8   | Monte Carlo Simulation . . . . .      | 35 |

# 1. The BA Add-In Functions

## 1.1. Linear Regression Functions

### 1.1.1. LinearRegTrain

The example illustrated below is available on the *add-in webpage* by downloading the *Linear and Logistic Regression file* and going to the *linearReg* sheet.

**LinearRegTrain** is an array function that allows you to estimate the coefficients  $(\beta_0, \beta_1, \dots, \beta_K)$  of a regression equation of the form

$$Y = \beta_0 + \beta_1 \text{Var1} + \beta_2 \text{Var2} + \dots + \beta_K \text{VarK} + \epsilon,$$

using observed data on the independent variables (**Var1**, **Var2**, ..., **VarK**) and on the dependent variable **Y**. This function outputs the estimated coefficients, the standard errors, the associated p-values, and the R-squared of the regression.

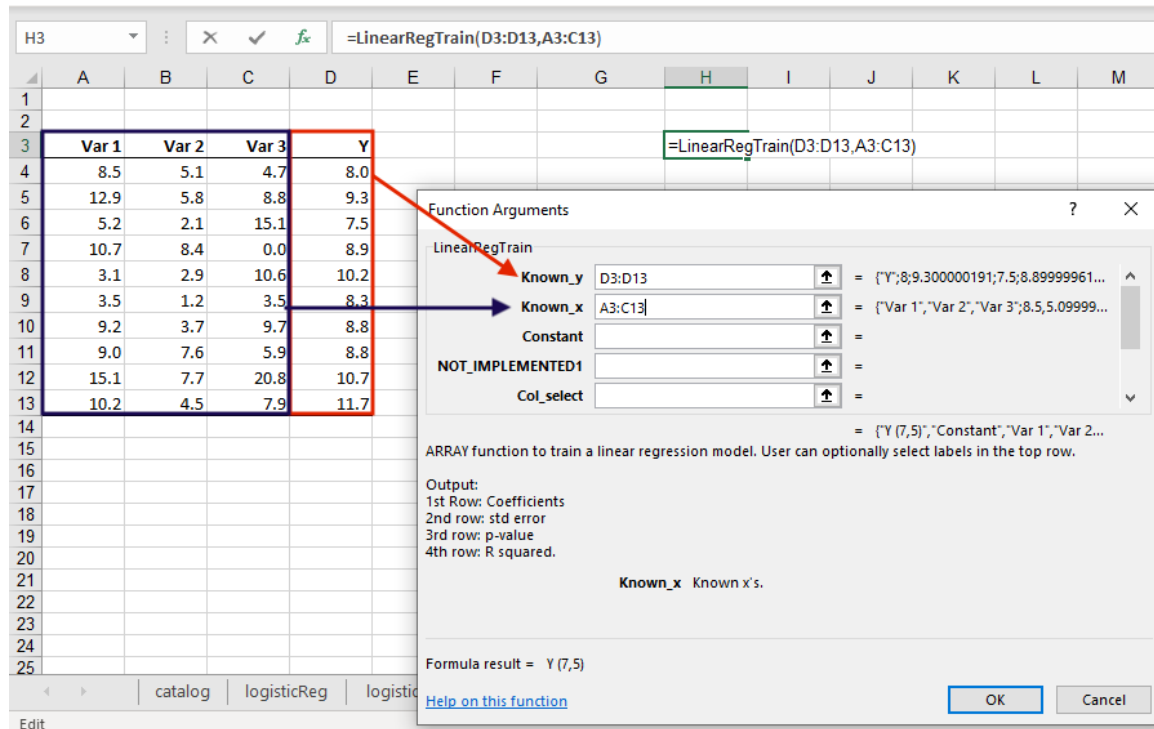
We illustrate how this function works with a dataset that contains 10 observations of 3 independent variables (**Var1**, **Var2**, **Var3**) and the dependent variable **Y**.

To use the function:

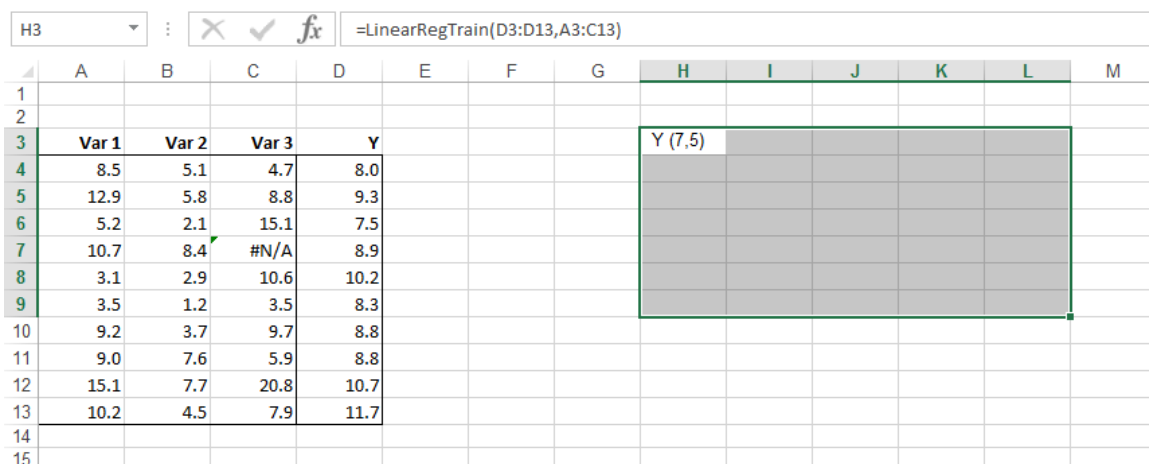
1. Select the cell where you want to display the output (H3 in the example) and call the function by typing `=LinearRegTrain(` and then clicking on the  $f_x$  symbol next to the formula bar. (Alternatively, you can call the function by clicking on the  $f_x$  symbol first, which will display a menu of all available functions, and then clicking on **LinearRegTrain**.)

|    |       |       |       |      |   |   |   |                  |   |   |   |
|----|-------|-------|-------|------|---|---|---|------------------|---|---|---|
| H3 |       |       |       |      |   |   |   |                  |   |   |   |
|    | A     | B     | C     | D    | E | F | G | H                | I | J | K |
| 1  |       |       |       |      |   |   |   |                  |   |   |   |
| 2  |       |       |       |      |   |   |   |                  |   |   |   |
| 3  | Var 1 | Var 2 | Var 3 | Y    |   |   |   | =LinearRegTrain( |   |   |   |
| 4  | 8.5   | 5.1   | 4.7   | 8.0  |   |   |   |                  |   |   |   |
| 5  | 12.9  | 5.8   | 8.8   | 9.3  |   |   |   |                  |   |   |   |
| 6  | 5.2   | 2.1   | 15.1  | 7.5  |   |   |   |                  |   |   |   |
| 7  | 10.7  | 8.4   | 0.0   | 8.9  |   |   |   |                  |   |   |   |
| 8  | 3.1   | 2.9   | 10.6  | 10.2 |   |   |   |                  |   |   |   |
| 9  | 3.5   | 1.2   | 3.5   | 8.3  |   |   |   |                  |   |   |   |
| 10 | 9.2   | 3.7   | 9.7   | 8.8  |   |   |   |                  |   |   |   |
| 11 | 9.0   | 7.6   | 5.9   | 8.8  |   |   |   |                  |   |   |   |
| 12 | 15.1  | 7.7   | 20.8  | 10.7 |   |   |   |                  |   |   |   |
| 13 | 10.2  | 4.5   | 7.9   | 11.7 |   |   |   |                  |   |   |   |
| 14 |       |       |       |      |   |   |   |                  |   |   |   |
| 15 |       |       |       |      |   |   |   |                  |   |   |   |
| 16 |       |       |       |      |   |   |   |                  |   |   |   |
| 17 |       |       |       |      |   |   |   |                  |   |   |   |

- When you call the function, the window **Function Arguments** will appear. Follow the instructions to populate the input fields, then click OK.



- The string `Y (7,5)` will appear in cell H3, where Y is the name of the variable in cell D3. This indicates that you should select an output array of 7 rows and 5 columns. Select the output array starting from cell H3 as the next figure shows.



- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the output. *Remark: for recent versions of Excel, this step is not necessary.*

|    | A     | B     | C     | D    | E | F | G | H                | I        | J        | K        | L        |
|----|-------|-------|-------|------|---|---|---|------------------|----------|----------|----------|----------|
| 1  |       |       |       |      |   |   |   |                  |          |          |          |          |
| 2  |       |       |       |      |   |   |   |                  |          |          |          |          |
| 3  | Var 1 | Var 2 | Var 3 | Y    |   |   |   | Y (7,5)          | Constant | Var 1    | Var 2    | Var 3    |
| 4  | 8.5   | 5.1   | 4.7   | 8.0  |   |   |   | Coefficients     | 7.837367 | 0.120385 | -0.00744 | 0.042174 |
| 5  | 12.9  | 5.8   | 8.8   | 9.3  |   |   |   | Std error        | 1.292461 | 0.229497 | 0.348021 | 0.091981 |
| 6  | 5.2   | 2.1   | 15.1  | 7.5  |   |   |   | p-value          | 0.09%    | 61.87%   | 98.36%   | 66.27%   |
| 7  | 10.7  | 8.4   | 0.0   | 8.9  |   |   |   | R-sqr            | 0.197115 |          |          |          |
| 8  | 3.1   | 2.9   | 10.6  | 10.2 |   |   |   | Number valid obs | 10       |          |          |          |
| 9  | 3.5   | 1.2   | 3.5   | 8.3  |   |   |   | Total obs        | 10       |          |          |          |
| 10 | 9.2   | 3.7   | 9.7   | 8.8  |   |   |   |                  |          |          |          |          |
| 11 | 9.0   | 7.6   | 5.9   | 8.8  |   |   |   |                  |          |          |          |          |
| 12 | 15.1  | 7.7   | 20.8  | 10.7 |   |   |   |                  |          |          |          |          |
| 13 | 10.2  | 4.5   | 7.9   | 11.7 |   |   |   |                  |          |          |          |          |
| 14 |       |       |       |      |   |   |   |                  |          |          |          |          |
| 15 |       |       |       |      |   |   |   |                  |          |          |          |          |

The second row of the output contains the estimates of the coefficients: the column (**Constant**) refers to the coefficient  $\beta_0$ , while the columns (**Var1,Var2,Var3**) refer to the coefficients ( $\beta_1, \beta_2, \beta_3$ ) respectively. In the following rows we have standard errors and p-values of the estimates as well as the  $R^2$  of the regression. The last two rows contain the number of valid observations and the total number of observations respectively.

You can also format the output to display only three decimals and to display percentages.

**Optional Input: Col\_select.** The optional input **Col\_select** allows you to specify which variables you want to include in your regression. For example, the configuration below runs a logistic regression with only **Var1** and **Var3** as independent variables.

|    | A     | B     | C     | D                                    | E | F | G | H     | I        | J     | K     | L     |
|----|-------|-------|-------|--------------------------------------|---|---|---|-------|----------|-------|-------|-------|
| 1  | 1     | 0     | 1     | column select (1 include, 0 exclude) |   |   |   |       |          |       |       |       |
| 2  |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 3  | Var 1 | Var 2 | Var 3 | Y                                    |   |   |   | A1:C1 | Constant | Var 1 | Var 2 | Var 3 |
| 4  | 8.5   | 5.1   | 4.7   | 8.0                                  |   |   |   |       |          |       |       |       |
| 5  | 12.9  | 5.8   | 8.8   | 9.3                                  |   |   |   |       |          |       |       |       |
| 6  | 5.2   | 2.1   | 15.1  | 7.5                                  |   |   |   |       |          |       |       |       |
| 7  | 10.7  | 8.4   | 0.0   | 8.9                                  |   |   |   |       |          |       |       |       |
| 8  | 3.1   | 2.9   | 10.6  | 10.2                                 |   |   |   |       |          |       |       |       |
| 9  | 3.5   | 1.2   | 3.5   | 8.3                                  |   |   |   |       |          |       |       |       |
| 10 | 9.2   | 3.7   | 9.7   | 8.8                                  |   |   |   |       |          |       |       |       |
| 11 | 9.0   | 7.6   | 5.9   | 8.8                                  |   |   |   |       |          |       |       |       |
| 12 | 15.1  | 7.7   | 20.8  | 10.7                                 |   |   |   |       |          |       |       |       |
| 13 | 10.2  | 4.5   | 7.9   | 11.7                                 |   |   |   |       |          |       |       |       |
| 14 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 15 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 16 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 17 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 18 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 19 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 20 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 21 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 22 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 23 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 24 |       |       |       |                                      |   |   |   |       |          |       |       |       |
| 25 |       |       |       |                                      |   |   |   |       |          |       |       |       |

Function Arguments

LinearRegTrain

Known\_y D3:D13 = {"Y";8;9.300000191;7.5;8.899999961...

Known\_x A3:C13 = {"Var 1","Var 2","Var 3";8.5;5.09999...

Constant NOT\_IMPLEMENTED1 =

Col\_select A1:C1 = {1,0,1}

= {"Y (7,4)","Constant","Var 1","Var 3...

ARRAY function to train a linear regression model. User can optionally select labels in the top row.

Output:  
1st Row: Coefficients  
2nd row: std error  
3rd row: p-value  
4th row: R squared.

Col\_select A vector of 0/1. If omitted, all columns in Known\_x are considered for regression.If specified, and if the jth entry is 0 in this vector, the jth column in Known\_x matrix is ignored.

Formula result = Y (7,4)

[Help on this function](#)

OK Cancel

## 1.1.2. LinearRegPredict

The example illustrated below is available on the *add-in webpage* by downloading the *Linear and Logistic Regression* file and going to the *linearReg* sheet.

**LinearRegPredict** uses the coefficients ( $\beta_0^e, \beta_1^e, \dots, \beta_K^e$ ) that we estimate with **LinearRegTrain** and the data on the independent variables (**Var1**, **Var2**, ..., **VarK**) to compute a prediction for the dependent variable using the formula

$$Y^P = \beta_0^e + \beta_1^e \text{Var1} + \beta_2^e \text{Var2} + \dots + \beta_K^e \text{VarK}.$$

For example, using the coefficients that we estimated in the **LinearRegTrain** example we would predict **Y** using the following formula

$$Y^P = 7.854 + 0.114\text{Var1} + 0.023\text{Var2} + 0.034\text{Var3},$$

which, for the first observation, yields a prediction of

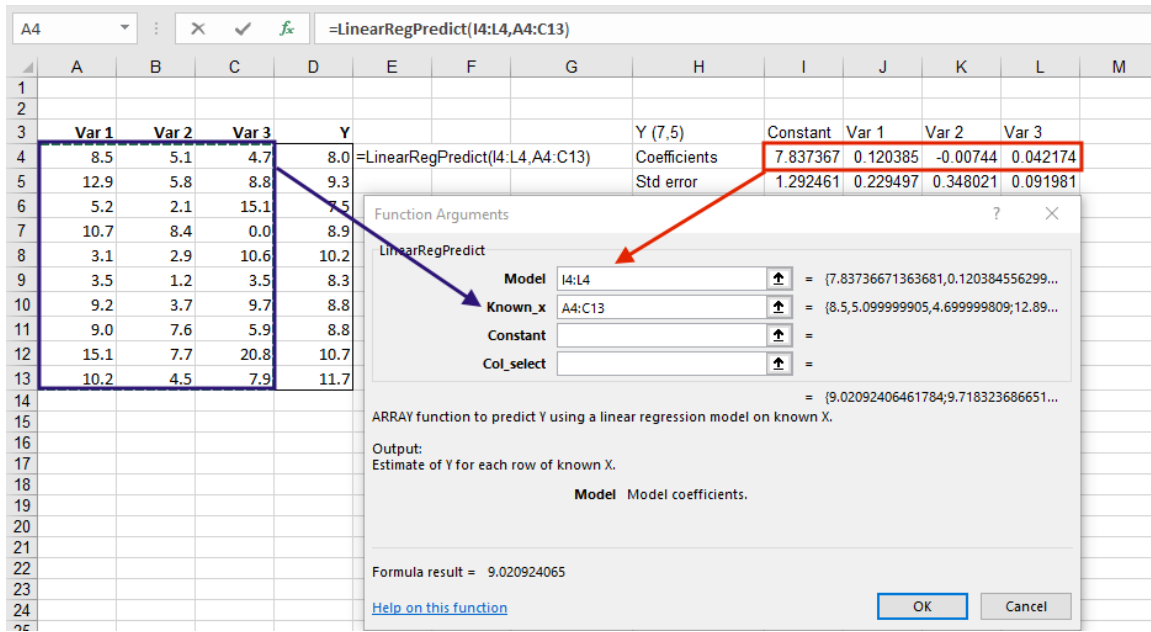
$$9.1001 = 7.854 + 0.114 * 8.5 + 0.023 * 5.1 + 0.034 * 4.7.$$

To use the function:

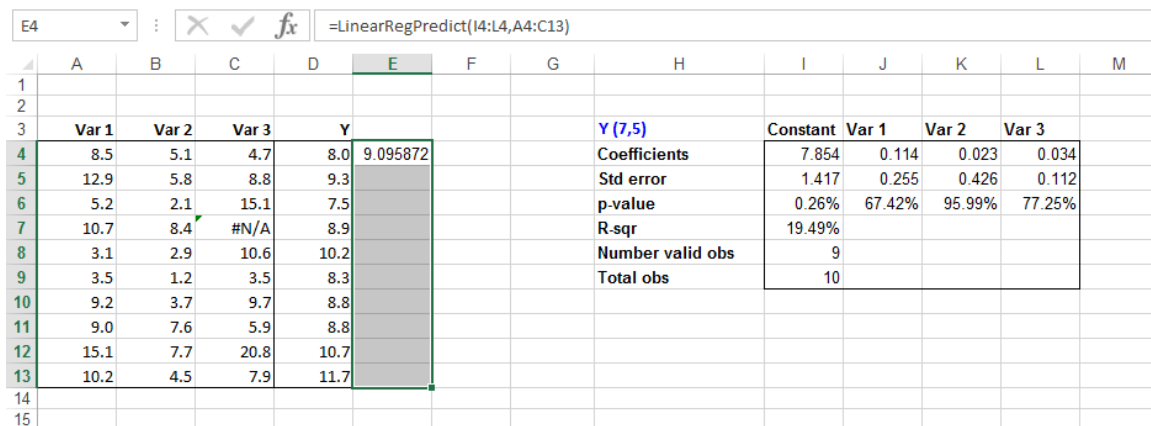
1. Select the first cell in which you want the output to be displayed; call the function by typing `=LinearRegPredict(` in the formula bar and then pressing the  $f_x$  symbol next to the formula bar.

|     |       |       |       |                      |                    |   |   |                  |          |          |          |          |   |
|-----|-------|-------|-------|----------------------|--------------------|---|---|------------------|----------|----------|----------|----------|---|
| SUM | :     | X     | ✓     | <i>f<sub>x</sub></i> | =LinearRegPredict( |   |   |                  |          |          |          |          |   |
| 1   | A     | B     | C     | D                    | E                  | F | G | H                | I        | J        | K        | L        | M |
| 2   |       |       |       |                      |                    |   |   |                  |          |          |          |          |   |
| 3   | Var 1 | Var 2 | Var 3 | Y                    |                    |   |   | Y (7,5)          | Constant | Var 1    | Var 2    | Var 3    |   |
| 4   | 8.5   | 5.1   | 4.7   | 8.0                  | =LinearRegPredict( |   |   | Coefficients     | 7.837367 | 0.120385 | -0.00744 | 0.042174 |   |
| 5   | 12.9  | 5.8   | 8.8   | 9.3                  |                    |   |   | Std error        | 1.292461 | 0.229497 | 0.348021 | 0.091981 |   |
| 6   | 5.2   | 2.1   | 15.1  | 7.5                  |                    |   |   | p-value          | 0.09%    | 61.87%   | 98.36%   | 66.27%   |   |
| 7   | 10.7  | 8.4   | 0.0   | 8.9                  |                    |   |   | R-sqr            | 0.197115 |          |          |          |   |
| 8   | 3.1   | 2.9   | 10.6  | 10.2                 |                    |   |   | Number valid obs | 10       |          |          |          |   |
| 9   | 3.5   | 1.2   | 3.5   | 8.3                  |                    |   |   | Total obs        | 10       |          |          |          |   |
| 10  | 9.2   | 3.7   | 9.7   | 8.8                  |                    |   |   |                  |          |          |          |          |   |
| 11  | 9.0   | 7.6   | 5.9   | 8.8                  |                    |   |   |                  |          |          |          |          |   |
| 12  | 15.1  | 7.7   | 20.8  | 10.7                 |                    |   |   |                  |          |          |          |          |   |
| 13  | 10.2  | 4.5   | 7.9   | 11.7                 |                    |   |   |                  |          |          |          |          |   |
| 14  |       |       |       |                      |                    |   |   |                  |          |          |          |          |   |
| 15  |       |       |       |                      |                    |   |   |                  |          |          |          |          |   |
| 16  |       |       |       |                      |                    |   |   |                  |          |          |          |          |   |

2. Follow the instructions to populate the input fields, as demonstrated in the figure below, then click OK.



- Remember that this is an array function. Select the column in which you want the output to be displayed: this should be a column of the same length as the number of observations that will contain the predictions associated to each observation. In the figure below, we have 10 observations and we select cells E4:E13.



- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the predictions. You can also add a title (for example "LinearRegPredict") to the output-column and format the output-cells to display only the first 3 decimals, as in the figure below. *Remark: for recent versions of Excel, this step is not necessary.*

|    |       |       |       |      |          |   |   |                  |          |          |          |          |   |
|----|-------|-------|-------|------|----------|---|---|------------------|----------|----------|----------|----------|---|
| E4 |       |       |       |      |          |   |   |                  |          |          |          |          |   |
|    | A     | B     | C     | D    | E        | F | G | H                | I        | J        | K        | L        | M |
| 1  |       |       |       |      |          |   |   |                  |          |          |          |          |   |
| 2  |       |       |       |      |          |   |   |                  |          |          |          |          |   |
| 3  | Var 1 | Var 2 | Var 3 | Y    |          |   |   | Y (7,5)          | Constant | Var 1    | Var 2    | Var 3    |   |
| 4  | 8.5   | 5.1   | 4.7   | 8.0  | 9.020924 |   |   | Coefficients     | 7.837367 | 0.120385 | -0.00744 | 0.042174 |   |
| 5  | 12.9  | 5.8   | 8.8   | 9.3  | 9.718324 |   |   | Std error        | 1.292461 | 0.229497 | 0.348021 | 0.091981 |   |
| 6  | 5.2   | 2.1   | 15.1  | 7.5  | 9.084577 |   |   | p-value          | 0.09%    | 61.87%   | 98.36%   | 66.27%   |   |
| 7  | 10.7  | 8.4   | 0.0   | 8.9  | 9.063009 |   |   | R-sqr            | 0.197115 |          |          |          |   |
| 8  | 3.1   | 2.9   | 10.6  | 10.2 | 8.636036 |   |   | Number valid obs | 10       |          |          |          |   |
| 9  | 3.5   | 1.2   | 3.5   | 8.3  | 8.397397 |   |   | Total obs        | 10       |          |          |          |   |
| 10 | 9.2   | 3.7   | 9.7   | 8.8  | 9.326475 |   |   |                  |          |          |          |          |   |
| 11 | 9.0   | 7.6   | 5.9   | 8.8  | 9.113132 |   |   |                  |          |          |          |          |   |
| 12 | 15.1  | 7.7   | 20.8  | 10.7 | 10.47513 |   |   |                  |          |          |          |          |   |
| 13 | 10.2  | 4.5   | 7.9   | 11.7 | 9.364997 |   |   |                  |          |          |          |          |   |
| 14 |       |       |       |      |          |   |   |                  |          |          |          |          |   |
| 15 |       |       |       |      |          |   |   |                  |          |          |          |          |   |
| 16 |       |       |       |      |          |   |   |                  |          |          |          |          |   |

**Optional Input: Col\_select.** See explanation at the end of Section 1.1.1.

## 1.2. Logistic Regression Functions

### 1.2.1. LogisticRegTrain

*The example illustrated below is available on the add-in webpage by downloading the Linear and Logistic Regression file and going to the logisticReg sheet.*

**LogisticRegTrain** is an array function that allows you to estimate the coefficients ( $\beta_0, \beta_1, \dots, \beta_K$ ) of a logistic regression model using observed data on the independent variables (**Var1, Var2, ..., VarK**) and on the dependent variable **Y**. Note that the dependent variable in a logistic regression must be binary, i.e. it must take values 0 or 1. This function outputs the estimated coefficients, the standard errors, and the associated p-values. This function allows you to estimate the probability that the dependent variable is equal to 1 as

$$Pr(\text{dependent variable equals one}) = \frac{\exp(w)}{1 + \exp(w)},$$

with

$$w = \beta_0 + \beta_1 \text{Var1} + \beta_2 \text{Var2} + \dots + \beta_K \text{VarK}.$$

We illustrate how this function works with a dataset that contains 18 observations of 3 independent variables (**Var1, Var2, Var3**) and the dependent variable **Y**.

To use the function:

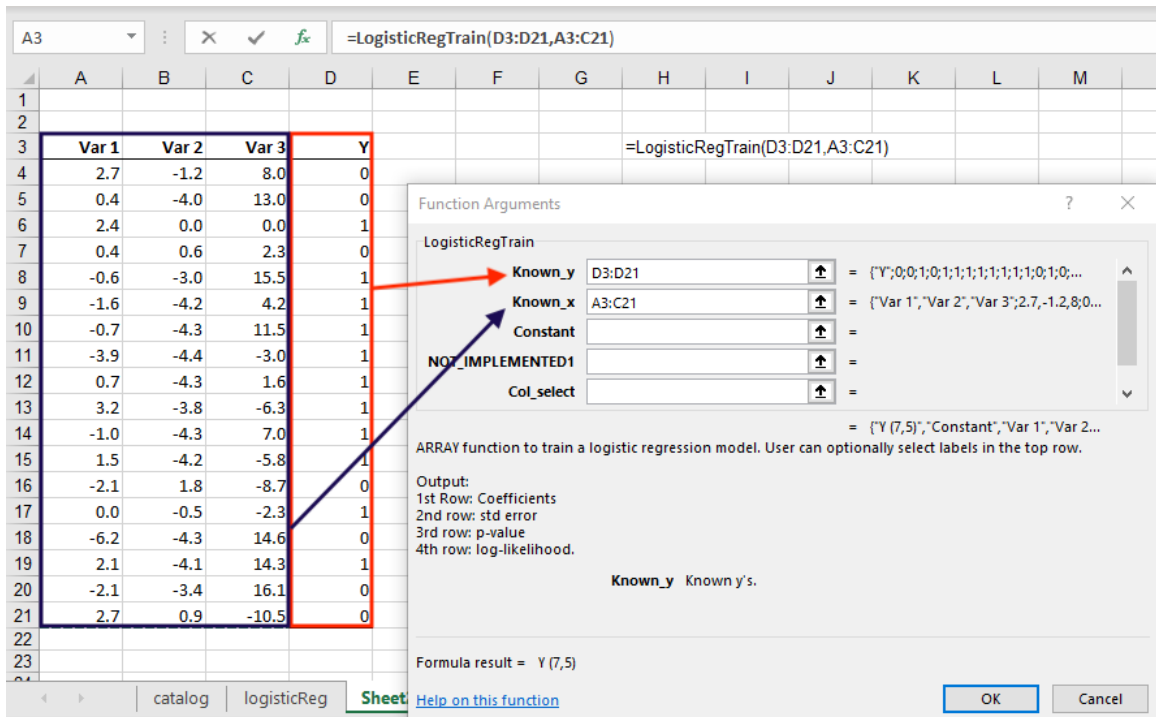
1. Select the cell where you want to display the output (H3 in the example) and call the function by typing **=LogisticRegTrain(** and then clicking on the  $f_x$  symbol next to the formula bar. (Alternatively, you can call the function by clicking on the  $f_x$



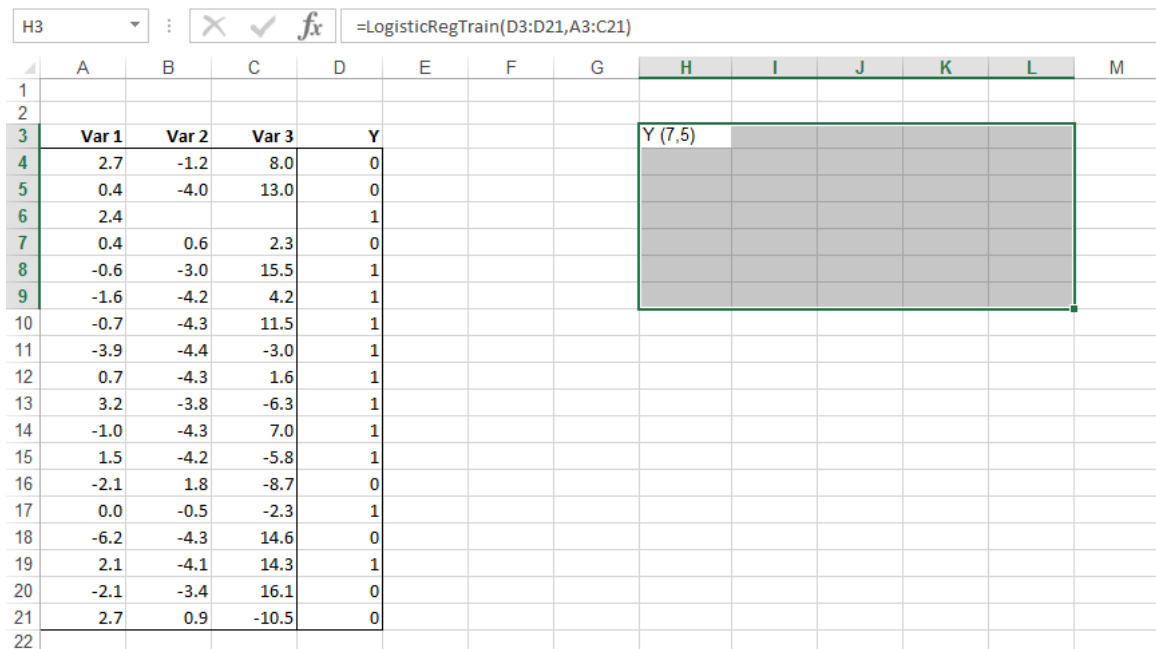
symbol first, which will display a menu of all available functions, and then clicking on LogisticRegTrain.)

|                    |       |       |       |   |   |   |   |                    |   |   |
|--------------------|-------|-------|-------|---|---|---|---|--------------------|---|---|
| SUM                |       |       |       |   |   |   |   |                    |   |   |
| =LogisticRegTrain( |       |       |       |   |   |   |   |                    |   |   |
|                    | A     | B     | C     | D | E | F | G | H                  | I | J |
| 1                  |       |       |       |   |   |   |   |                    |   |   |
| 2                  |       |       |       |   |   |   |   |                    |   |   |
| 3                  | Var 1 | Var 2 | Var 3 | Y |   |   |   | =LogisticRegTrain( |   |   |
| 4                  | 2.7   | -1.2  | 8.0   | 0 |   |   |   |                    |   |   |
| 5                  | 0.4   | -4.0  | 13.0  | 0 |   |   |   |                    |   |   |
| 6                  | 2.4   | 0.0   | 0.0   | 1 |   |   |   |                    |   |   |
| 7                  | 0.4   | 0.6   | 2.3   | 0 |   |   |   |                    |   |   |
| 8                  | -0.6  | -3.0  | 15.5  | 1 |   |   |   |                    |   |   |
| 9                  | -1.6  | -4.2  | 4.2   | 1 |   |   |   |                    |   |   |
| 10                 | -0.7  | -4.3  | 11.5  | 1 |   |   |   |                    |   |   |
| 11                 | -3.9  | -4.4  | -3.0  | 1 |   |   |   |                    |   |   |
| 12                 | 0.7   | -4.3  | 1.6   | 1 |   |   |   |                    |   |   |
| 13                 | 3.2   | -3.8  | -6.3  | 1 |   |   |   |                    |   |   |
| 14                 | -1.0  | -4.3  | 7.0   | 1 |   |   |   |                    |   |   |
| 15                 | 1.5   | -4.2  | -5.8  | 1 |   |   |   |                    |   |   |
| 16                 | -2.1  | 1.8   | -8.7  | 0 |   |   |   |                    |   |   |
| 17                 | 0.0   | -0.5  | -2.3  | 1 |   |   |   |                    |   |   |
| 18                 | -6.2  | -4.3  | 14.6  | 0 |   |   |   |                    |   |   |
| 19                 | 2.1   | -4.1  | 14.3  | 1 |   |   |   |                    |   |   |
| 20                 | -2.1  | -3.4  | 16.1  | 0 |   |   |   |                    |   |   |
| 21                 | 2.7   | 0.9   | -10.5 | 0 |   |   |   |                    |   |   |
| 22                 |       |       |       |   |   |   |   |                    |   |   |

- When you call the function, the window **Function Arguments** will appear. Follow the instructions to populate the input fields, then click OK.



- The string Y(7,5) will appear in cell H3, where Y is the name of the variable in cell D3. This indicates that you should select an output array of 7 rows and 5 columns. Select the output array starting from cell H3 as the next figure shows.



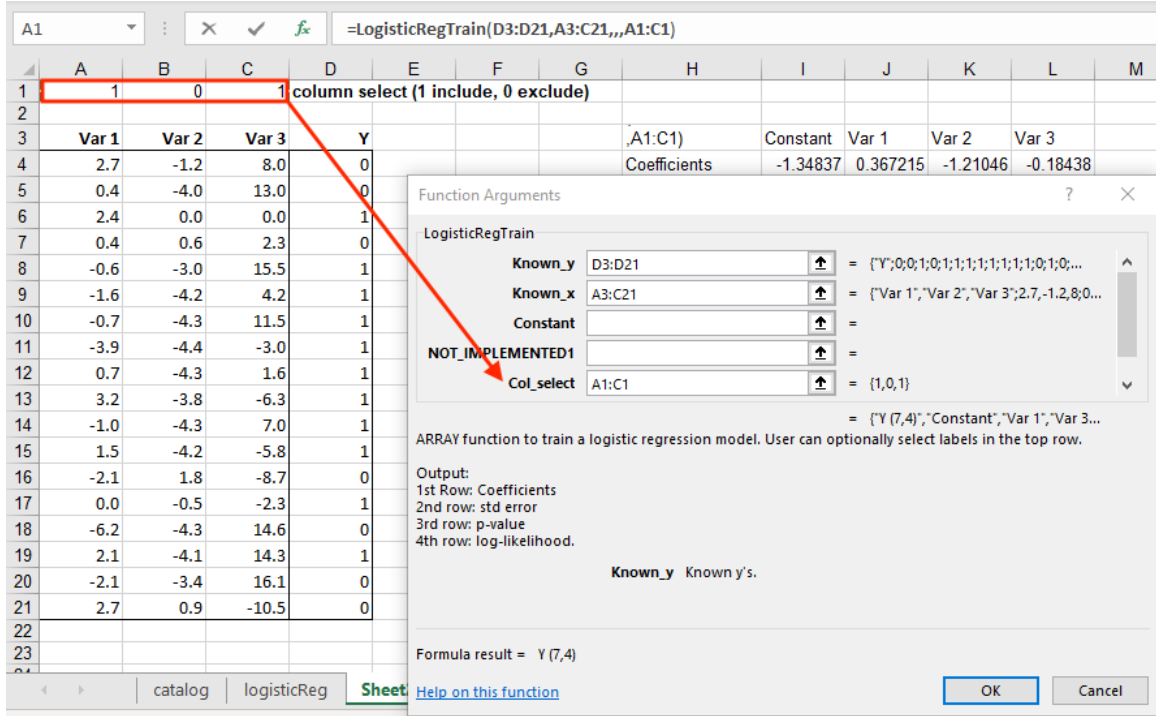
- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the output. *Remark: for recent versions of Excel, this step is not necessary.*

|     |       |       |       |   |   |   |   |                  |          |          |          |          |   |
|-----|-------|-------|-------|---|---|---|---|------------------|----------|----------|----------|----------|---|
| N11 |       |       |       |   |   |   |   |                  |          |          |          |          |   |
|     | A     | B     | C     | D | E | F | G | H                | I        | J        | K        | L        | M |
| 1   |       |       |       |   |   |   |   |                  |          |          |          |          |   |
| 2   |       |       |       |   |   |   |   |                  |          |          |          |          |   |
| 3   | Var 1 | Var 2 | Var 3 | Y |   |   |   | Y (7,5)          | Constant | Var 1    | Var 2    | Var 3    |   |
| 4   | 2.7   | -1.2  | 8.0   | 0 |   |   |   | Coefficients     | -1.34837 | 0.367215 | -1.21046 | -0.18438 |   |
| 5   | 0.4   | -4.0  | 13.0  | 0 |   |   |   | Std error        | 1.054453 | 0.314121 | 0.588221 | 0.124832 |   |
| 6   | 2.4   | 0.0   | 0.0   | 1 |   |   |   | p-value          | 20.10%   | 24.24%   | 3.96%    | 13.97%   |   |
| 7   | 0.4   | 0.6   | 2.3   | 0 |   |   |   | Log-likelihood   | -7.36825 |          |          |          |   |
| 8   | -0.6  | -3.0  | 15.5  | 1 |   |   |   | Number valid obs | 18       |          |          |          |   |
| 9   | -1.6  | -4.2  | 4.2   | 1 |   |   |   | Total obs        | 18       |          |          |          |   |
| 10  | -0.7  | -4.3  | 11.5  | 1 |   |   |   |                  |          |          |          |          |   |
| 11  | -3.9  | -4.4  | -3.0  | 1 |   |   |   |                  |          |          |          |          |   |
| 12  | 0.7   | -4.3  | 1.6   | 1 |   |   |   |                  |          |          |          |          |   |
| 13  | 3.2   | -3.8  | -6.3  | 1 |   |   |   |                  |          |          |          |          |   |
| 14  | -1.0  | -4.3  | 7.0   | 1 |   |   |   |                  |          |          |          |          |   |
| 15  | 1.5   | -4.2  | -5.8  | 1 |   |   |   |                  |          |          |          |          |   |
| 16  | -2.1  | 1.8   | -8.7  | 0 |   |   |   |                  |          |          |          |          |   |
| 17  | 0.0   | -0.5  | -2.3  | 1 |   |   |   |                  |          |          |          |          |   |
| 18  | -6.2  | -4.3  | 14.6  | 0 |   |   |   |                  |          |          |          |          |   |
| 19  | 2.1   | -4.1  | 14.3  | 1 |   |   |   |                  |          |          |          |          |   |
| 20  | -2.1  | -3.4  | 16.1  | 0 |   |   |   |                  |          |          |          |          |   |
| 21  | 2.7   | 0.9   | -10.5 | 0 |   |   |   |                  |          |          |          |          |   |
| 22  |       |       |       |   |   |   |   |                  |          |          |          |          |   |

The second row of the output contains the estimates of the coefficients: the column (**Constant**) refers to the coefficient  $\beta_0$ , while the columns (**Var1,Var2,Var3**) refer to the coefficients ( $\beta_1, \beta_2, \beta_3$ ) respectively. In the following rows we have standard errors and p-values of the estimates. The last two rows contain the number of valid observations and the total number of observations respectively.

You can also format the output to display only three decimals and to display percentages.

**Optional Input: Col\_select.** The optional input **Col\_select** allows you to specify which variables you want to include in your regression. For example, the configuration below runs a logistic regression with only **Var1** and **Var3** as independent variables.



## 1.2.2. LogisticRegPredict

The example illustrated below is available on the *add-in webpage* by downloading the *Linear and Logistic Regression* file and going to the *logisticReg* sheet.

**LogisticRegPredict** uses the coefficients  $(\beta_0^e, \beta_1^e, \dots, \beta_K^e)$  that we estimate with **LogisticRegTrain** and the data on the independent variables (**Var1**, **Var2**, ..., **VarK**) to compute a prediction  $p$  for the probability that the dependent variable is equal to 1. The prediction is calculated in two steps:

- (i) Obtain the exponent  $w$  of the logistic function as

$$w = \beta_0^e + \beta_1^e \text{Var1} + \beta_2^e \text{Var2} + \dots + \beta_K^e \text{VarK}.$$

- (ii) Calculate the probability that  $Y=1$  as follows

$$p = \frac{\exp(w)}{1 + \exp(w)}.$$

For example, using the coefficients that we estimated in the **LogisticRegTrain** example we would predict  $p$  for the first observation in the example as follows

$$w = -2.047 + 0.301 * 2.7 - 1.432 * (-1.2) - 0.207 * 8 = -1.172$$

and

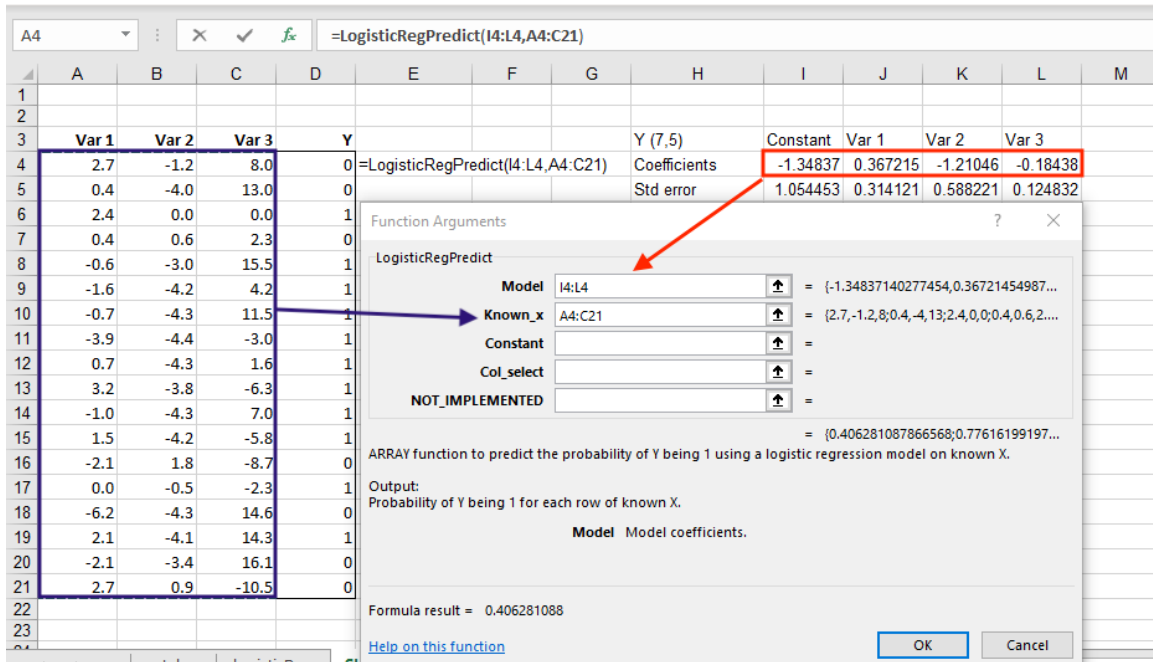
$$p = \frac{\exp(-1.172)}{1 + \exp(-1.172)} = 23.61\%$$

To use the function:

1. Select the first cell in which you want the output to be displayed; call the function by typing `=LogisticRegPredict(` in the formula bar and then pressing the  $f_x$  symbol next to the formula bar.

|                                |       |       |       |   |                      |   |   |                  |          |          |          |          |   |
|--------------------------------|-------|-------|-------|---|----------------------|---|---|------------------|----------|----------|----------|----------|---|
| SUM                            |       |       |       |   |                      |   |   |                  |          |          |          |          |   |
| X ✓ $f_x$ =LogisticRegPredict( |       |       |       |   |                      |   |   |                  |          |          |          |          |   |
|                                | A     | B     | C     | D | E                    | F | G | H                | I        | J        | K        | L        | M |
| 1                              |       |       |       |   |                      |   |   |                  |          |          |          |          |   |
| 2                              |       |       |       |   |                      |   |   |                  |          |          |          |          |   |
| 3                              | Var 1 | Var 2 | Var 3 | Y |                      |   |   | Y (7,5)          | Constant | Var 1    | Var 2    | Var 3    |   |
| 4                              | 2.7   | -1.2  | 8.0   | 0 | =LogisticRegPredict( |   |   | Coefficients     | -1.34837 | 0.367215 | -1.21046 | -0.18438 |   |
| 5                              | 0.4   | -4.0  | 13.0  | 0 |                      |   |   | Std error        | 1.054453 | 0.314121 | 0.588221 | 0.124832 |   |
| 6                              | 2.4   | 0.0   | 0.0   | 1 |                      |   |   | p-value          | 20.10%   | 24.24%   | 3.96%    | 13.97%   |   |
| 7                              | 0.4   | 0.6   | 2.3   | 0 |                      |   |   | Log-likelihood   | -7.36825 |          |          |          |   |
| 8                              | -0.6  | -3.0  | 15.5  | 1 |                      |   |   | Number valid obs | 18       |          |          |          |   |
| 9                              | -1.6  | -4.2  | 4.2   | 1 |                      |   |   | Total obs        | 18       |          |          |          |   |
| 10                             | -0.7  | -4.3  | 11.5  | 1 |                      |   |   |                  |          |          |          |          |   |
| 11                             | -3.9  | -4.4  | -3.0  | 1 |                      |   |   |                  |          |          |          |          |   |
| 12                             | 0.7   | -4.3  | 1.6   | 1 |                      |   |   |                  |          |          |          |          |   |
| 13                             | 3.2   | -3.8  | -6.3  | 1 |                      |   |   |                  |          |          |          |          |   |
| 14                             | -1.0  | -4.3  | 7.0   | 1 |                      |   |   |                  |          |          |          |          |   |
| 15                             | 1.5   | -4.2  | -5.8  | 1 |                      |   |   |                  |          |          |          |          |   |
| 16                             | -2.1  | 1.8   | -8.7  | 0 |                      |   |   |                  |          |          |          |          |   |
| 17                             | 0.0   | -0.5  | -2.3  | 1 |                      |   |   |                  |          |          |          |          |   |
| 18                             | -6.2  | -4.3  | 14.6  | 0 |                      |   |   |                  |          |          |          |          |   |
| 19                             | 2.1   | -4.1  | 14.3  | 1 |                      |   |   |                  |          |          |          |          |   |
| 20                             | -2.1  | -3.4  | 16.1  | 0 |                      |   |   |                  |          |          |          |          |   |
| 21                             | 2.7   | 0.9   | -10.5 | 0 |                      |   |   |                  |          |          |          |          |   |
| 22                             |       |       |       |   |                      |   |   |                  |          |          |          |          |   |

2. Follow the instructions to populate the input fields, as demonstrated in the figure below, then click OK.



- Remember that this is an array function. Select the column in which you want the output to be displayed: this should be a column of the same length as the number of observations that will contain the predictions associated to each observation. In the figure below, we have 18 observations and we select cells E4:E21.

| E4                                |       |       |       |   |          |   |   |                  |          |        |
|-----------------------------------|-------|-------|-------|---|----------|---|---|------------------|----------|--------|
| =LogisticRegPredict(I4:L4,A4:C21) |       |       |       |   |          |   |   |                  |          |        |
|                                   | A     | B     | C     | D | E        | F | G | H                | I        | J      |
| 1                                 |       |       |       |   |          |   |   |                  |          |        |
| 2                                 |       |       |       |   |          |   |   |                  |          |        |
| 3                                 | Var 1 | Var 2 | Var 3 | Y |          |   |   | Y (7,5)          | Constant | Var 1  |
| 4                                 | 2.7   | -1.2  | 8.0   | 0 | 0.236122 |   |   |                  | -2.047   | 0.301  |
| 5                                 | 0.4   | -4.0  | 13.0  | 0 |          |   |   | Coefficients     | 1.300    | 0.322  |
| 6                                 | 2.4   |       |       | 1 |          |   |   | Std error        | 11.53%   | 35.02% |
| 7                                 | 0.4   | 0.6   | 2.3   | 0 |          |   |   | p-value          | -6.159   | 3.86%  |
| 8                                 | -0.6  | -3.0  | 15.5  | 1 |          |   |   | Log-likelihood   | 17       | 14.27% |
| 9                                 | -1.6  | -4.2  | 4.2   | 1 |          |   |   | Number valid obs | 18       |        |
| 10                                | -0.7  | -4.3  | 11.5  | 1 |          |   |   | Total obs        |          |        |
| 11                                | -3.9  | -4.4  | -3.0  | 1 |          |   |   |                  |          |        |
| 12                                | 0.7   | -4.3  | 1.6   | 1 |          |   |   |                  |          |        |
| 13                                | 3.2   | -3.8  | -6.3  | 1 |          |   |   |                  |          |        |
| 14                                | -1.0  | -4.3  | 7.0   | 1 |          |   |   |                  |          |        |
| 15                                | 1.5   | -4.2  | -5.8  | 1 |          |   |   |                  |          |        |
| 16                                | -2.1  | 1.8   | -8.7  | 0 |          |   |   |                  |          |        |
| 17                                | 0.0   | -0.5  | -2.3  | 1 |          |   |   |                  |          |        |
| 18                                | -6.2  | -4.3  | 14.6  | 0 |          |   |   |                  |          |        |
| 19                                | 2.1   | -4.1  | 14.3  | 1 |          |   |   |                  |          |        |
| 20                                | -2.1  | -3.4  | 16.1  | 0 |          |   |   |                  |          |        |
| 21                                | 2.7   | 0.9   | -10.5 | 0 |          |   |   |                  |          |        |

- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the predictions. You can also add a title (for example "LogisticRegPredict") to the output-column and format the output-cells to display percentages, as in the figure below. *Remark: for recent versions of Excel, this step is not necessary.*

|    | A     | B     | C     | D | E           | F | G | H                | I        | J        | K        | L        | M |
|----|-------|-------|-------|---|-------------|---|---|------------------|----------|----------|----------|----------|---|
| 1  |       |       |       |   |             |   |   |                  |          |          |          |          |   |
| 2  |       |       |       |   |             |   |   |                  |          |          |          |          |   |
| 3  | Var 1 | Var 2 | Var 3 | Y |             |   |   | Y (7,5)          | Constant | Var 1    | Var 2    | Var 3    |   |
| 4  | 2.7   | -1.2  | 8.0   | 0 | 0.406281088 |   |   | Coefficients     | -1.34837 | 0.367215 | -1.21046 | -0.18438 |   |
| 5  | 0.4   | -4.0  | 13.0  | 0 | 0.776161992 |   |   | Std error        | 1.054453 | 0.314121 | 0.588221 | 0.124832 |   |
| 6  | 2.4   | 0.0   | 0.0   | 1 | 0.385313171 |   |   | p-value          | 20.10%   | 24.24%   | 3.96%    | 13.97%   |   |
| 7  | 0.4   | 0.6   | 2.3   | 0 | 0.086920689 |   |   | Log-likelihood   | -7.36825 |          |          |          |   |
| 8  | -0.6  | -3.0  | 15.5  | 1 | 0.311058582 |   |   | Number valid obs | 18       |          |          |          |   |
| 9  | -1.6  | -4.2  | 4.2   | 1 | 0.91479336  |   |   | Total obs        | 18       |          |          |          |   |
| 10 | -0.7  | -4.3  | 11.5  | 1 | 0.814452492 |   |   |                  |          |          |          |          |   |
| 11 | -3.9  | -4.4  | -3.0  | 1 | 0.956836256 |   |   |                  |          |          |          |          |   |
| 12 | 0.7   | -4.3  | 1.6   | 1 | 0.9785141   |   |   |                  |          |          |          |          |   |
| 13 | 3.2   | -3.8  | -6.3  | 1 | 0.996271542 |   |   |                  |          |          |          |          |   |
| 14 | -1.0  | -4.3  | 7.0   | 1 | 0.900136079 |   |   |                  |          |          |          |          |   |
| 15 | 1.5   | -4.2  | -5.8  | 1 | 0.995301276 |   |   |                  |          |          |          |          |   |
| 16 | -2.1  | 1.8   | -8.7  | 0 | 0.063312717 |   |   |                  |          |          |          |          |   |
| 17 | 0.0   | -0.5  | -2.3  | 1 | 0.420900958 |   |   |                  |          |          |          |          |   |
| 18 | -6.2  | -4.3  | 14.6  | 0 | 0.247490071 |   |   |                  |          |          |          |          |   |
| 19 | 2.1   | -4.1  | 14.3  | 1 | 0.851834057 |   |   |                  |          |          |          |          |   |
| 20 | -2.1  | -3.4  | 16.1  | 0 | 0.274394336 |   |   |                  |          |          |          |          |   |
| 21 | 2.7   | 0.9   | -10.5 | 0 | 0.620025405 |   |   |                  |          |          |          |          |   |
| 22 |       |       |       |   |             |   |   |                  |          |          |          |          |   |

**Optional Input: Col\_select.** See explanation at the end of Section 1.2.1.

## 1.3. K-Nearest Neighbor Functions (Content-based)

*Tip:* The functions in this section do content-based prediction, which means that they predict a score (or rating) based on other known attributes of content. The dependent variable (score or rating) and the independent variables (other attributes) are distinct, and in general you need information on both to be able to use these functions.

### 1.3.1. knn\_in

The example illustrated below is available on the *add-in webpage* by downloading the *Classification, KNN, Misc file* and going to the *knn sheet*.

**knn\_in** applies the **k**-nearest neighbor algorithm to make predictions within a specified sample. The inputs of the function are: the parameter **k** of nearest neighbor to match; the known variables (**Var1**, **Var2**, ..., **VarM**), on the basis of which the observations are matched; the known outcomes **Y**. The nearest neighbor to a given observation are the observations which have minimum Euclidean distance

$$d(i, j) = \sqrt{(\text{Var1}_i - \text{Var1}_j)^2 + (\text{Var2}_i - \text{Var2}_j)^2 + \dots + (\text{VarM}_i - \text{VarM}_j)^2}$$

and the prediction  $p$  is computed as a simple average of the **k**-nearest neighbor outcomes

$$p = \frac{Y_1 + Y_2 + \dots + Y_k}{k}.$$

To use the function:

1. Write the parameter **k** in an empty cell, **k=3** in the example below; select the first cell in which you want the output to be displayed; call the function by typing **=knn\_in(** in the formula bar and then pressing the  **$f_x$**  symbol next to the formula bar.

|    | A     | B     | C    | D        | E | F |
|----|-------|-------|------|----------|---|---|
| 1  |       |       |      |          |   |   |
| 2  |       |       |      |          |   |   |
| 3  |       |       | k    | 3        |   |   |
| 4  |       |       |      |          |   |   |
| 5  | Var 1 | Var 2 | Y    |          |   |   |
| 6  |       | 9.4   | 11.9 | =knn_in( |   |   |
| 7  |       | 10.8  | 10.2 | 5        |   |   |
| 8  |       | 6.1   | 10   | 3        |   |   |
| 9  |       | 11    | 4    | 3        |   |   |
| 10 |       | 3.7   | 11.8 | 3        |   |   |
| 11 |       | 11.4  | 2.9  | 3        |   |   |
| 12 |       | 5.5   | 6    | 2        |   |   |
| 13 |       | 5.1   | 2    | 1        |   |   |
| 14 |       | 10.7  | 7.7  | 4        |   |   |
| 15 |       | 2.5   | 10.4 | 3        |   |   |
| 16 |       | 4.1   | 8.6  | 3        |   |   |
| 17 |       | 7.3   | 5    | 2        |   |   |
| 18 |       | 2.2   | 4.1  | 2        |   |   |
| 19 |       |       |      |          |   |   |

2. Follow the instructions to populate the input fields, as demonstrated in the figure below, then click OK.

The screenshot shows the Excel KNN algorithm interface. The main window displays a data table with columns Var 1, Var 2, and Y. A red circle highlights the value 'k' in cell D3, which is the predicted Y value. A blue arrow points from the 'K' input in the Function Arguments dialog to the 'k' in the data table. The Function Arguments dialog shows Known\_y as C6:C18, Known\_x as A6:B18, and K as D3. The output is Y predictions.

- Remember that this is an array function. Select the column in which you want the output to be displayed: this should be a column of the same length as the number of observations. In the figure below, we selected cells D6:D18.



|    |       |       |   |      |   |   |
|----|-------|-------|---|------|---|---|
| D6 |       |       |   |      |   |   |
|    | A     | B     | C | D    | E | F |
| 1  |       |       |   |      |   |   |
| 2  |       |       |   |      |   |   |
| 3  |       |       | k | 3    |   |   |
| 4  |       |       |   |      |   |   |
| 5  | Var 1 | Var 2 | Y |      |   |   |
| 6  | 9.4   | 11.9  | 5 | 4.00 |   |   |
| 7  | 10.8  | 10.2  | 5 |      |   |   |
| 8  | 6.1   | 10.0  | 3 |      |   |   |
| 9  | 11.0  | 4.0   | 3 |      |   |   |
| 10 | 3.7   | 11.8  | 3 |      |   |   |
| 11 | 11.4  | 2.9   | 3 |      |   |   |
| 12 | 5.5   | 6.0   | 2 |      |   |   |
| 13 | 5.1   | 2.0   | 1 |      |   |   |
| 14 | 10.7  | 7.7   | 4 |      |   |   |
| 15 | 2.5   | 10.4  | 3 |      |   |   |
| 16 | 4.1   | 8.6   | 3 |      |   |   |
| 17 | 7.3   | 5.0   | 2 |      |   |   |
| 18 | 2.2   | 4.1   | 2 |      |   |   |
| 19 |       |       |   |      |   |   |
| 20 |       |       |   |      |   |   |

4. Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the predictions. You can also add a title (for example “knn\_in predict”) to the output-column and format the output-cells to display only the first two decimals. *Remark: for recent versions of Excel, this step is not necessary.*

|    |       |       |   |      |   |   |
|----|-------|-------|---|------|---|---|
| G6 |       |       |   |      |   |   |
|    | A     | B     | C | D    | E | F |
| 1  |       |       |   |      |   |   |
| 2  |       |       |   |      |   |   |
| 3  |       |       | k | 3    |   |   |
| 4  |       |       |   |      |   |   |
| 5  | Var 1 | Var 2 | Y |      |   |   |
| 6  | 9.4   | 11.9  | 5 | 4.00 |   |   |
| 7  | 10.8  | 10.2  | 5 | 4.00 |   |   |
| 8  | 6.1   | 10.0  | 3 | 3.00 |   |   |
| 9  | 11.0  | 4.0   | 3 | 3.00 |   |   |
| 10 | 3.7   | 11.8  | 3 | 3.00 |   |   |
| 11 | 11.4  | 2.9   | 3 | 3.00 |   |   |
| 12 | 5.5   | 6.0   | 2 | 2.33 |   |   |
| 13 | 5.1   | 2.0   | 1 | 2.00 |   |   |
| 14 | 10.7  | 7.7   | 4 | 3.33 |   |   |
| 15 | 2.5   | 10.4  | 3 | 3.00 |   |   |
| 16 | 4.1   | 8.6   | 3 | 2.67 |   |   |
| 17 | 7.3   | 5.0   | 2 | 2.00 |   |   |
| 18 | 2.2   | 4.1   | 2 | 2.00 |   |   |
| 19 |       |       |   |      |   |   |

### 1.3.2. knn\_in\_rmse

The example illustrated below is available on the add-in webpage by downloading the *Classification, KNN, Misc* file and going to the *knn\_full* sheet.

**knn\_in\_rmse** is a function that computes the Root Mean Squared Error (RMSE) for k-nearest neighbor predictions (as the ones you can obtain with **knn\_in**).

The inputs of the function are: the known variables (**Var1**, **Var2**, ..., **VarM**) on the basis of which the observations are matched; the known outcomes **Y**; the parameter **k** for which we want to compute the RMSE of predictions.

For a given **k**, the error is computed as follows

$$RMSE = \sqrt{\frac{(Y_1 - p_1)^2 + (Y_2 - p_2)^2 + \dots + (Y_N - p_N)^2}{N}},$$

where  $N$  is the total number of observations.

*Note:* this is not an array function and can be evaluated in a single stand-alone cell, in which case it outputs the RMSE for a specified  $k$ . However, it is particularly useful when you want to compare RMSEs for different  $k$ . We will illustrate how to do this in the example below.

To use the function:

1. Write a list of parameters  $k$  for which you want to compute the RMSE,  $k = 1, 2, \dots, 10$  in the example below; select the cell next to the first value for  $k$ ; call the function by typing `=knn_in_rmse(` in the formula bar and then pressing the  **$f_x$**  symbol next to the formula bar.

|    | A     | B     | C | D | E  | F             | G | H |
|----|-------|-------|---|---|----|---------------|---|---|
| 1  |       |       |   |   |    |               |   |   |
| 2  |       |       |   |   |    |               |   |   |
| 3  | Var 1 | Var 2 | Y |   | k  |               |   |   |
| 4  | 9.4   | 11.9  | 5 |   | 1  | =knn_in_rmse( |   |   |
| 5  | 10.8  | 10.2  | 5 |   | 2  |               |   |   |
| 6  | 6.1   | 10    | 3 |   | 3  |               |   |   |
| 7  | 11    | 4     | 3 |   | 4  |               |   |   |
| 8  | 3.7   | 11.8  | 3 |   | 5  |               |   |   |
| 9  | 11.4  | 2.9   | 3 |   | 6  |               |   |   |
| 10 | 5.5   | 6     | 2 |   | 7  |               |   |   |
| 11 | 5.1   | 2     | 1 |   | 8  |               |   |   |
| 12 | 10.7  | 7.7   | 4 |   | 9  |               |   |   |
| 13 | 2.5   | 10.4  | 3 |   | 10 |               |   |   |
| 14 | 4.1   | 8.6   | 3 |   |    |               |   |   |
| 15 | 7.3   | 5     | 2 |   |    |               |   |   |
| 16 | 2.2   | 4.1   | 2 |   |    |               |   |   |
| 17 |       |       |   |   |    |               |   |   |
| 18 |       |       |   |   |    |               |   |   |
| 19 |       |       |   |   |    |               |   |   |

2. Input the references to the cells that contain the independent and dependent variable data, as in the figure below, then *lock* the cell references with \$ signs. Input the reference of the cell that contains the first value for  $k$ , and make sure that this is *not* locked. Then click OK.

Function Arguments

**knn\_in\_rmse**

Known\_y: \$C\$4:\$C\$16

Known\_x: \$A\$4:\$B\$16

Normalize: ☐ (selected)

NOT\_IMPLEMENTED1: ☐ (selected)

Function to compute RMSE for output Y values computed using KNN algorithm.

Known\_x: Known X values.

Formula result = 0.480384461

Help on this function

OK Cancel

3. The function will display the output in the selected cell (F4). Copy the content of the cell down until cell F13, the formula will automatically update the calculation for every  $k$ . You can also format the output to display only three decimals.

|    |       |       |   |   |    |       |   |   |
|----|-------|-------|---|---|----|-------|---|---|
| F4 |       |       |   |   |    |       |   |   |
|    | A     | B     | C | D | E  | F     | G | H |
| 1  |       |       |   |   |    |       |   |   |
| 2  |       |       |   |   |    |       |   |   |
| 3  | Var 1 | Var 2 | Y |   | k  |       |   |   |
| 4  | 9.4   | 11.9  | 5 |   | 1  | 0.480 |   |   |
| 5  | 10.8  | 10.2  | 5 |   | 2  | 0.519 |   |   |
| 6  | 6.1   | 10    | 3 |   | 3  | 0.531 |   |   |
| 7  | 11    | 4     | 3 |   | 4  | 0.676 |   |   |
| 8  | 3.7   | 11.8  | 3 |   | 5  | 0.779 |   |   |
| 9  | 11.4  | 2.9   | 3 |   | 6  | 0.859 |   |   |
| 10 | 5.5   | 6     | 2 |   | 7  | 0.924 |   |   |
| 11 | 5.1   | 2     | 1 |   | 8  | 0.956 |   |   |
| 12 | 10.7  | 7.7   | 4 |   | 9  | 1.008 |   |   |
| 13 | 2.5   | 10.4  | 3 |   | 10 | 1.026 |   |   |
| 14 | 4.1   | 8.6   | 3 |   |    |       |   |   |
| 15 | 7.3   | 5     | 2 |   |    |       |   |   |
| 16 | 2.2   | 4.1   | 2 |   |    |       |   |   |
| 17 |       |       |   |   |    |       |   |   |

### 1.3.3. knn\_out

The example illustrated below is available on the add-in webpage by downloading the *Classification, KNN, Misc* file and going to the *knn\_full* sheet.

**knn\_out** applies the-k nearest neighbor algorithm to make predictions on the outcome variable Y of a new set of observations using a known sample.

To use the function:

1. Write the parameter **k** in an empty cell, **k=3** in the example below. Select the first cell in which you want the output to be displayed; call the function by typing **=knn\_out(** in the formula bar and then pressing the  $f_x$  symbol next to the formula bar.

|     |       |       |   |     |           |   |       |           |   |   |   |   |
|-----|-------|-------|---|-----|-----------|---|-------|-----------|---|---|---|---|
| SUM | :     | X     | ✓ | f_x | =knn_out( |   |       |           |   |   |   |   |
| 1   | A     | B     | C | D   | E         | F   | G     | H         | I | J | K | L |
| 2   |       |       |   |     |           |   |       |           |   |   |   |   |
| 3   |       |       | k | 3   |           | Out-of-sample predictions   |       |           |   |   |   |   |
| 4   |       |       |   |     |           | (Use the model based on 13 obserations to predict 6 new observations) |       |           |   |   |   |   |
| 5   | Var 1 | Var 2 | Y |     |           | Var 1   | Var 2 | =knn_out( |   |   |   |   |
| 6   | 9.4   | 11.9  | 5 |     |           | 9.3   | 2.7   |           |   |   |   |   |
| 7   | 10.8  | 10.2  | 5 |     |           | 5.3   | 10.2  |           |   |   |   |   |
| 8   | 6.1   | 10    | 3 |     |           | 11.9  | 3.4   |           |   |   |   |   |
| 9   | 11    | 4     | 3 |     |           | 4.1   | 2.2   |           |   |   |   |   |
| 10  | 3.7   | 11.8  | 3 |     |           | 6.6   | 4.3   |           |   |   |   |   |
| 11  | 11.4  | 2.9   | 3 |     |           | 8.3   | 5.4   |           |   |   |   |   |
| 12  | 5.5   | 6     | 2 |     |           |   |       |           |   |   |   |   |
| 13  | 5.1   | 2     | 1 |     |           |   |       |           |   |   |   |   |
| 14  | 10.7  | 7.7   | 4 |     |           |   |       |           |   |   |   |   |
| 15  | 2.5   | 10.4  | 3 |     |           |   |       |           |   |   |   |   |
| 16  | 4.1   | 8.6   | 3 |     |           |   |       |           |   |   |   |   |
| 17  | 7.3   | 5     | 2 |     |           |   |       |           |   |   |   |   |
| 18  | 2.2   | 4.1   | 2 |     |           |   |       |           |   |   |   |   |
| 19  |       |       |   |     |           |   |       |           |   |   |   |   |

2. The function takes as inputs the new observations **X**, the old observations and the known outcomes, as well as the parameter **k**. Follow the instructions to populate the input fields, as demonstrated in the figure below, then click **OK**.

Excel spreadsheet showing the setup for the KNN algorithm. The formula bar shows `=knn_out(F6:G11,C6:C18,A6:B18,D3)`. The spreadsheet contains data for 13 observations (rows 6-18) with columns Var 1, Var 2, and Y. A new observation (row 19) is being predicted. The function arguments dialog box is open, showing the following arguments:

- Known\_y**: F6:G11 (Range)
- Known\_x**: C6:C18 (Range)
- Known\_x**: A6:B18 (Range)
- Normalize**: K D3 (Value)

The formula result is 2.666666667.

- Remember that this is an array function. Select the column in which you want the output to be displayed: this should be a column of the same length as the number of new observations.

Excel spreadsheet showing the setup for the KNN algorithm. The formula bar shows `=knn_out(E6:F11,C6:C18,A6:B18,C3)`. The spreadsheet contains data for 13 observations (rows 6-18) with columns Var 1, Var 2, and Y. A new observation (row 19) is being predicted. The function arguments dialog box is open, showing the following arguments:

- Known\_y**: E6:F11 (Range)
- Known\_x**: C6:C18 (Range)
- Known\_x**: A6:B18 (Range)
- Normalize**: C3 (Value)

The formula result is 2.666666667.

- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the predictions. You can also format the output to display only two decimals. *Remark: for recent versions of Excel, this step is not necessary.*

Excel spreadsheet showing the setup for the KNN algorithm. The formula bar shows `=knn_out(F6:G11,C6:C18,A6:B18,D3)`. The spreadsheet contains data for 13 observations (rows 6-18) with columns Var 1, Var 2, and Y. A new observation (row 19) is being predicted. The function arguments dialog box is open, showing the following arguments:

- Known\_y**: F6:G11 (Range)
- Known\_x**: C6:C18 (Range)
- Known\_x**: A6:B18 (Range)
- Normalize**: D3 (Value)

The formula result is 2.666666667.

## 1.4. K-Nearest Neighbor Functions (User-based)

*Tip:* The functions in this section do user-based prediction, which means that they predict a score (or rating) based on the scores of other users. These function do not use any other content-attribute (as movie characteristics). You should use these functions when you want to predict ratings (for example, movie ratings) based only on the ratings of other users.

### 1.4.1. knn\_in\_movie

The example illustrated below is available on the [add-in webpage](#) by downloading the *Classification, KNN, Misc* file and going to the *knn\_in\_movie* sheet.

**knn\_in\_movie** uses the **k**-nearest neighbor algorithm to make predictions within a specified sample of users' ratings.

To use the function:

1. Write the parameter **k** in an empty cell, **k=3** in the example below; select the first cell in which you want the output to be displayed; call the function by typing **=knn\_in\_movie(** in the formula bar and then pressing the **f<sub>x</sub>** symbol next to the formula bar.

|     |                   |        |          |                |                |         |         |         |   |   |          |         |          |         |         |         |   |  |  |
|-----|-------------------|--------|----------|----------------|----------------|---------|---------|---------|---|---|----------|---------|----------|---------|---------|---------|---|--|--|
| SUM | :                 | X      | ✓        | f <sub>x</sub> | =knn_in_movie( |         |         |         |   |   |          |         |          |         |         |         |   |  |  |
|     | A                 | B      | C        | D              | E              | F       | G       | H       | I | J | K        | L       | M        | N       | O       | P       | Q |  |  |
| 1   |                   |        |          |                |                |         |         |         |   |   |          |         |          |         |         |         |   |  |  |
| 2   |                   |        |          |                |                |         |         |         |   |   |          |         |          |         |         |         |   |  |  |
| 3   |                   |        |          |                |                |         |         |         |   |   |          |         |          |         |         |         |   |  |  |
| 4   |                   |        |          |                |                |         | k       |         | 3 |   |          |         |          |         |         |         |   |  |  |
| 5   | Movie rating data |        | Movie 1  | Movie 2        | Movie 3        | Movie 4 | Movie 5 | Movie 6 |   |   | Movie 1  | Movie 2 | Movie 3  | Movie 4 | Movie 5 | Movie 6 |   |  |  |
| 6   | User              | User   | Godfathe |                | Bourne         | Pretty  | Working | Moneyba |   |   | Godfathe |         | Bourne   | Pretty  | Working | Moneyba |   |  |  |
| 7   | number            | name   | r        | Top Gun        | Identity       | Woman   | Girl    | Il      |   |   | r        | Top Gun | Identity | Woman   | Girl    | Il      |   |  |  |
| 8   | 1                 | Paul   | 5        | 2              |                | 1       | 0       |         |   |   | Paul     |         |          |         |         |         |   |  |  |
| 9   | 2                 | Ben    | 5        |                | 5              |         |         | 2       |   |   | Ben      |         |          |         |         |         |   |  |  |
| 10  | 3                 | Jane   | 4        | 2              |                | 2       | 5       | 3       |   |   | Jane     |         |          |         |         |         |   |  |  |
| 11  | 4                 | Guilga |          | 3              | 3              | 3       | 3       | 4       |   |   | Guilga   |         |          |         |         |         |   |  |  |
| 12  | 5                 | Thomas | 4        | 4              |                | 4       |         |         |   |   | Thomas   |         |          |         |         |         |   |  |  |
| 13  | 6                 | Marisa | 4        | 3              | 2              |         |         | 4       |   |   | Marisa   |         |          |         |         |         |   |  |  |
| 14  | 7                 | Lucas  | 1        | 0              | 3              |         | 3       | 2       |   |   | Lucas    |         |          |         |         |         |   |  |  |
| 15  | 8                 | Emma   | 4        | 5              | 4              | 5       |         | 4       |   |   | Emma     |         |          |         |         |         |   |  |  |
| 16  | 9                 | Olivia | 5        | 2              | 2              |         |         |         |   |   | Olivia   |         |          |         |         |         |   |  |  |
| 17  | 10                | Lewis  | 4        | 3              |                | 3       |         | 0       |   |   | Lewis    |         |          |         |         |         |   |  |  |

2. Follow the instructions to populate the input fields, as demonstrated in the figure below, then click OK.

Excel screenshot showing the formula bar with `=knn_in_movie(C7:H16,H3)` and the Function Arguments dialog box. The dialog box shows the Known\_x argument as `K:H3` and the K argument as `3`. The formula result is `4.666666667`.

| User number | User name | Movie 1<br>Godfather | Movie 2<br>Top Gun | Movie 3<br>Bourne Identity | Movie 4<br>Pretty Woman | Movie 5<br>Working Girl | Movie 6<br>Moneyball |
|-------------|-----------|----------------------|--------------------|----------------------------|-------------------------|-------------------------|----------------------|
| 1           | Paul      | 5                    | 2                  |                            | 1                       | 0                       |                      |
| 2           | Ben       | 5                    |                    | 5                          |                         |                         | 2                    |
| 3           | Jane      | 4                    | 2                  |                            | 2                       | 5                       | 3                    |
| 4           | Guiga     |                      | 3                  | 3                          | 3                       | 3                       | 4                    |
| 5           | Thomas    | 4                    | 4                  |                            | 4                       |                         |                      |
| 6           | Marisa    | 4                    | 3                  | 2                          |                         |                         | 4                    |
| 7           | Lucas     |                      | 1                  | 0                          | 3                       | 3                       | 2                    |
| 8           | Emma      | 4                    | 5                  | 4                          | 5                       |                         | 4                    |
| 9           | Olivia    | 5                    | 2                  | 2                          | 2                       |                         |                      |
| 10          | Lewis     | 4                    | 3                  |                            | 3                       |                         | 0                    |

- Remember that this is an array function. Select the area in which you want the output to be displayed: this should have the same number of rows and columns as the area that contains the users' ratings. In the figure below, we selected cells K7:P16.

Excel screenshot showing the formula bar with `=knn_in_movie(C7:H16,H3)` and the output area K7:P16. The output area is highlighted in green, showing the predicted rating for Paul (4.67) and the predicted ratings for the other users.

| User number | User name | Movie 1<br>Godfather | Movie 2<br>Top Gun | Movie 3<br>Bourne Identity | Movie 4<br>Pretty Woman | Movie 5<br>Working Girl | Movie 6<br>Moneyball |
|-------------|-----------|----------------------|--------------------|----------------------------|-------------------------|-------------------------|----------------------|
| 1           | Paul      | 5                    | 2                  |                            | 1                       | 0                       |                      |
| 2           | Ben       | 5                    |                    | 5                          |                         |                         | 2                    |
| 3           | Jane      | 4                    | 2                  |                            | 2                       | 5                       | 3                    |
| 4           | Guiga     |                      | 3                  | 3                          | 3                       | 3                       | 4                    |
| 5           | Thomas    | 4                    | 4                  |                            | 4                       |                         |                      |
| 6           | Marisa    | 4                    | 3                  | 2                          |                         |                         | 4                    |
| 7           | Lucas     |                      | 1                  | 0                          | 3                       | 3                       | 2                    |
| 8           | Emma      | 4                    | 5                  | 4                          | 5                       |                         | 4                    |
| 9           | Olivia    | 5                    | 2                  | 2                          | 2                       |                         |                      |
| 10          | Lewis     | 4                    | 3                  |                            | 3                       |                         | 0                    |

- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the predictions. You can also add a title to the output-column and format the output-cells to display only the first two decimals. *Remark: for recent versions of Excel, this step is not necessary.*

Excel screenshot showing the formula bar with `=knn_in_movie(C7:H16,H3)` and the output area K7:P16. The output area is highlighted in green, showing the predicted ratings for the users.

| User number | User name | Movie 1<br>Godfather | Movie 2<br>Top Gun | Movie 3<br>Bourne Identity | Movie 4<br>Pretty Woman | Movie 5<br>Working Girl | Movie 6<br>Moneyball |
|-------------|-----------|----------------------|--------------------|----------------------------|-------------------------|-------------------------|----------------------|
| 1           | Paul      | 5                    | 2                  |                            | 1                       | 0                       |                      |
| 2           | Ben       | 5                    |                    | 5                          |                         |                         | 2                    |
| 3           | Jane      | 4                    | 2                  |                            | 2                       | 5                       | 3                    |
| 4           | Guiga     |                      | 3                  | 3                          | 3                       | 3                       | 4                    |
| 5           | Thomas    | 4                    | 4                  |                            | 4                       |                         |                      |
| 6           | Marisa    | 4                    | 3                  | 2                          |                         |                         | 4                    |
| 7           | Lucas     |                      | 1                  | 0                          | 3                       | 3                       | 2                    |
| 8           | Emma      | 4                    | 5                  | 4                          | 5                       |                         | 4                    |
| 9           | Olivia    | 5                    | 2                  | 2                          | 2                       |                         |                      |
| 10          | Lewis     | 4                    | 3                  |                            | 3                       |                         | 0                    |

## 1.4.2. knn\_in\_movie\_rmse

The example illustrated below is available on the *add-in webpage* by downloading the *Classification, KNN, Misc* file and going to the *knn\_in\_movie* sheet.

**knn\_in\_movie\_rmse** is a function that computes the Root Mean Squared Error (RMSE) for k-nearest neighbor predictions (as the ones you can obtain with **knn\_in\_movie**).

The inputs of the function are the users' ratings for a set of movies and the parameter **k** for which we want to compute the RMSE of predictions.

*Note:* this is not an array function and can be evaluated in a single stand-alone cell, in which case it outputs the RMSE for a specified k. However, it is particularly useful when you want to compare RMSEs for different k. We will illustrate how to do this in the example below.

To use the function:

1. Write a list of parameters **k** for which you want to compute the RMSE,  $k = 1, 2, \dots, 9$  in the example below; select the cell next to the first value for **k**; call the function by typing **=knn\_in\_rmse(** in the formula bar and then pressing the **f<sub>x</sub>** symbol next to the formula bar.

|    | A | B                 | C         | D        | E       | F               | G            | H            | I       | J  | K | L                   | M |
|----|---|-------------------|-----------|----------|---------|-----------------|--------------|--------------|---------|----|---|---------------------|---|
| 1  |   |                   |           |          |         |                 |              |              |         |    |   |                     |   |
| 2  |   |                   |           |          |         |                 |              |              |         |    |   |                     |   |
| 3  |   | Movie rating data | Movie 1   | Movie 2  | Movie 3 | Movie 4         | Movie 5      | Movie 6      |         |    |   |                     |   |
| 4  |   | User number       | User name | Godfathe | Top Gun | Bourne Identity | Pretty Woman | Working Girl | Moneyba | II | k |                     |   |
| 5  |   | 1                 | Paul      | 5        | 2       |                 | 1            | 0            |         |    | 1 | =knn_in_movie_rmse( |   |
| 6  |   | 2                 | Ben       | 5        |         | 5               |              |              | 2       |    | 2 |                     |   |
| 7  |   | 3                 | Jane      | 4        | 2       |                 | 2            | 5            | 3       |    | 3 |                     |   |
| 8  |   | 4                 | Guiga     |          | 3       | 3               | 3            | 3            | 4       |    | 4 |                     |   |
| 9  |   | 5                 | Thomas    | 4        | 4       |                 | 4            |              |         |    | 5 |                     |   |
| 10 |   | 6                 | Marisa    | 4        | 3       | 2               |              |              | 4       |    | 6 |                     |   |
| 11 |   | 7                 | Lucas     |          | 1       | 0               | 3            | 3            | 2       |    | 7 |                     |   |
| 12 |   | 8                 | Emma      | 4        | 5       | 4               | 5            |              | 4       |    | 8 |                     |   |
| 13 |   | 9                 | Olivia    | 5        | 2       | 2               | 2            |              |         |    | 9 |                     |   |
| 14 |   | 10                | Lewis     | 4        | 3       |                 | 3            |              | 0       |    |   |                     |   |
| 15 |   |                   |           |          |         |                 |              |              |         |    |   |                     |   |

2. Input the references to the cells that contain the users' ratings, as in the figure below, then *lock* the cell references with \$ signs. Input the reference of the cell that contains the first value for **k**, and make sure that this is *not locked*. Then click OK.

Function Arguments

knn\_in\_movie\_rmse

Known\_x: \$C\$5:\$H\$14

Normalize: 1

NOT\_IMPLEMENTED1: 1

Weighted\_voting: 1

Function to compute RMSE for in\_movie ratings computed using KNN\_in\_movie algorithm.

Known\_x: Known X values.

Formula result = 1.112697281

Help on this function

OK Cancel

- The function will display the output in the selected cell (K5). Copy the content of the cell down until cell K13, the formula will automatically update the calculation for every k. You can also format the output to display only three decimals.

|    |                   |           |          |         |                 |              |              |         |    |   |          |  |
|----|-------------------|-----------|----------|---------|-----------------|--------------|--------------|---------|----|---|----------|--|
| K5 |                   |           |          |         |                 |              |              |         |    |   |          |  |
|    | A                 | B         | C        | D       | E               | F            | G            | H       | I  | J | K        |  |
| 1  |                   |           |          |         |                 |              |              |         |    |   |          |  |
| 2  |                   |           |          |         |                 |              |              |         |    |   |          |  |
| 3  | Movie rating data | Movie 1   | Movie 2  | Movie 3 | Movie 4         | Movie 5      | Movie 6      |         |    |   |          |  |
| 4  | User number       | User name | Godfathe | Top Gun | Bourne Identity | Pretty Woman | Working Girl | Moneyba | II |   | k        |  |
| 5  | 1                 | Paul      | 5        | 2       |                 | 1            | 0            |         |    | 1 | 1.112697 |  |
| 6  | 2                 | Ben       | 5        |         | 5               |              |              |         | 2  | 2 | 1.032219 |  |
| 7  | 3                 | Jane      | 4        | 2       |                 | 2            | 5            | 3       |    | 3 | 1.159274 |  |
| 8  | 4                 | Guiga     |          | 3       | 3               | 3            | 3            | 4       |    | 4 | 1.289649 |  |
| 9  | 5                 | Thomas    | 4        | 4       |                 | 4            |              |         |    | 5 | 1.424502 |  |
| 10 | 6                 | Marisa    | 4        | 3       | 2               |              |              | 4       |    | 6 | 1.453622 |  |
| 11 | 7                 | Lucas     |          | 1       | 0               | 3            | 3            | 2       |    | 7 | 1.474302 |  |
| 12 | 8                 | Emma      | 4        | 5       | 4               | 5            |              | 4       |    | 8 | 1.498432 |  |
| 13 | 9                 | Olivia    | 5        | 2       | 2               | 2            |              |         |    | 9 | 1.498432 |  |
| 14 | 10                | Lewis     | 4        | 3       |                 | 3            |              | 0       |    |   |          |  |
| 15 |                   |           |          |         |                 |              |              |         |    |   |          |  |

## 1.5. Other KNN Functions

The example illustrated below is available on the add-in webpage by downloading the Classification, KNN, Misc file and going to the knn\_full sheet.

### 1.5.1. knn\_dist

**knn\_dist** is an array function that uses users' ratings to compute the distance of each user from a given user that you specify.

To use the function:

- Decide the baseline user from which you want to compute the distances (we use **Jane** in the example below).
- Select the first cell in which you want the output to be displayed; call the function by typing **=knn\_dist(** in the formula bar and then pressing the **f<sub>x</sub>** symbol next to the formula bar.

|     |                   |           |          |         |                 |              |              |         |    |        |                  |   |
|-----|-------------------|-----------|----------|---------|-----------------|--------------|--------------|---------|----|--------|------------------|---|
| SUM |                   |           |          |         |                 |              |              |         |    |        |                  |   |
|     | A                 | B         | C        | D       | E               | F            | G            | H       | I  | J      | K                | L |
| 1   |                   |           |          |         |                 |              |              |         |    |        |                  |   |
| 2   |                   |           |          |         |                 |              |              |         |    |        |                  |   |
| 3   | Movie rating data | Movie 1   | Movie 2  | Movie 3 | Movie 4         | Movie 5      | Movie 6      |         |    |        |                  |   |
| 4   | User number       | User name | Godfathe | Top Gun | Bourne Identity | Pretty Woman | Working Girl | Moneyba | II |        | Distance to Jane |   |
| 5   | 1                 | Paul      | 5        | 2       |                 | 1            | 0            |         |    | Paul   | =knn_dist(       |   |
| 6   | 2                 | Ben       | 5        |         | 5               |              |              |         | 2  | Ben    |                  |   |
| 7   | 3                 | Jane      | 4        | 2       |                 | 2            | 5            | 3       |    | Jane   |                  |   |
| 8   | 4                 | Guiga     |          | 3       | 3               | 3            | 3            | 4       |    | Guiga  |                  |   |
| 9   | 5                 | Thomas    | 4        | 4       |                 | 4            |              |         |    | Thomas |                  |   |
| 10  | 6                 | Marisa    | 4        | 3       | 2               |              |              | 4       |    | Marisa |                  |   |
| 11  | 7                 | Lucas     |          | 1       | 0               | 3            | 3            | 2       |    | Lucas  |                  |   |
| 12  | 8                 | Emma      | 4        | 5       | 4               | 5            |              | 4       |    | Emma   |                  |   |
| 13  | 9                 | Olivia    | 5        | 2       | 2               | 2            |              |         |    | Olivia |                  |   |
| 14  | 10                | Lewis     | 4        | 3       |                 | 3            |              | 0       |    | Lewis  |                  |   |
| 15  |                   |           |          |         |                 |              |              |         |    |        |                  |   |



- Follow the instructions to populate the input fields, as demonstrated in the figure below, then click OK.

Function Arguments

Known\_x: C5:H14  
 Reference: C7:H7  
 Normalize: ☒  
 NOT\_IMPLEMENTED1: ☐  
 Dist\_Scale\_Vec: 1

ARRAY function to compute distance from Reference to each point in Known\_x  
 Output:  
 Distance from each point to Reference.

Known\_x Known X values.

Formula result = 2.598076211

OK Cancel

- Remember that this is an array function. Select the column in which you want the output to be displayed: this should be a column of the same length as the number of users. In the figure below, we selected cells K5:K14.

|    | A  | B                 | C         | D         | E       | F               | G            | H            | I         | J      | K    | L |
|----|----|-------------------|-----------|-----------|---------|-----------------|--------------|--------------|-----------|--------|------|---|
| 1  |    |                   |           |           |         |                 |              |              |           |        |      |   |
| 2  |    |                   |           |           |         |                 |              |              |           |        |      |   |
| 3  |    | Movie rating data | Movie 1   | Movie 2   | Movie 3 | Movie 4         | Movie 5      | Movie 6      |           |        |      |   |
| 4  |    | User number       | User name | Godfather | Top Gun | Bourne Identity | Pretty Woman | Working Girl | Moneyball |        |      |   |
| 5  | 1  | Paul              | 5         | 2         |         | 1               |              |              |           | Paul   | 0.82 |   |
| 6  | 2  | Ben               | 5         |           | 5       |                 |              |              | 2         | Ben    |      |   |
| 7  | 3  | Jane              | 4         | 2         |         | 2               | 5            | 3            |           | Jane   |      |   |
| 8  | 4  | Guiga             |           | 3         | 3       | 3               | 3            | 4            |           | Guiga  |      |   |
| 9  | 5  | Thomas            | 4         | 4         |         | 4               |              |              |           | Thomas |      |   |
| 10 | 6  | Marisa            | 4         | 3         | 2       |                 |              | 4            |           | Marisa |      |   |
| 11 | 7  | Lucas             |           | 1         | 0       | 3               | 3            | 2            |           | Lucas  |      |   |
| 12 | 8  | Emma              | 4         | 5         | 4       | 5               |              | 4            |           | Emma   |      |   |
| 13 | 9  | Olivia            | 5         | 2         | 2       | 2               |              |              |           | Olivia |      |   |
| 14 | 10 | Lewis             | 4         | 3         |         | 3               |              |              |           | Lewis  |      |   |

- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the predictions. You can also add a title to the output-column and format the output-cells to display only the first two decimals. *Remark: for recent versions of Excel, this step is not necessary.*

|    | A  | B                 | C         | D         | E       | F               | G            | H            | I         | J      | K    | L |
|----|----|-------------------|-----------|-----------|---------|-----------------|--------------|--------------|-----------|--------|------|---|
| 1  |    |                   |           |           |         |                 |              |              |           |        |      |   |
| 2  |    |                   |           |           |         |                 |              |              |           |        |      |   |
| 3  |    | Movie rating data | Movie 1   | Movie 2   | Movie 3 | Movie 4         | Movie 5      | Movie 6      |           |        |      |   |
| 4  |    | User number       | User name | Godfather | Top Gun | Bourne Identity | Pretty Woman | Working Girl | Moneyball |        |      |   |
| 5  | 1  | Paul              | 5         | 2         |         | 1               | 0            |              |           | Paul   | 2.60 |   |
| 6  | 2  | Ben               | 5         |           | 5       |                 |              | 2            |           | Ben    | 1.00 |   |
| 7  | 3  | Jane              | 4         | 2         |         | 2               | 5            | 3            |           | Jane   | 0.00 |   |
| 8  | 4  | Guiga             |           | 3         | 3       | 3               | 3            | 4            |           | Guiga  | 1.32 |   |
| 9  | 5  | Thomas            | 4         | 4         |         | 4               |              |              |           | Thomas | 1.63 |   |
| 10 | 6  | Marisa            | 4         | 3         | 2       |                 |              | 4            |           | Marisa | 0.82 |   |
| 11 | 7  | Lucas             |           | 1         | 0       | 3               | 3            | 2            |           | Lucas  | 1.32 |   |
| 12 | 8  | Emma              | 4         | 5         | 4       | 5               |              | 4            |           | Emma   | 2.18 |   |
| 13 | 9  | Olivia            | 5         | 2         | 2       | 2               |              |              |           | Olivia | 0.58 |   |
| 14 | 10 | Lewis             | 4         | 3         |         | 3               |              | 0            |           | Lewis  | 1.66 |   |

## 1.5.2. knn\_nearest

**knn\_nearest** is an array function that uses users' ratings to rank users in order of proximity (smallest distance) to a given user that you specify. The numbers returned are indices of the rows in the input table in order of distance. (Note, in particular, that they are not “ranks”.)

To use the function:

0. Decide the baseline user from which you want to compute the distance rankings (we use **Jane** in the example below).
1. Select the first cell in which you want the output to be displayed; call the function by typing `=knn_nearest(` in the formula bar and then pressing the  **$f_x$**  symbol next to the formula bar.

|    | A  | B                 | C         | D        | E               | F            | G               | H       | I | J | K | L |
|----|----|-------------------|-----------|----------|-----------------|--------------|-----------------|---------|---|---|---|---|
| 2  |    |                   |           |          |                 |              |                 |         |   |   |   |   |
| 3  |    | Movie rating data | Movie 1   | Movie 2  | Movie 3         | Movie 4      | Movie 5         | Movie 6 |   |   |   |   |
| 4  |    | User number       | User name | Godfathe | Bourne Identity | Pretty Woman | Working Moneyba | Girl II |   |   |   |   |
| 5  | 1  | Paul              | 5         | 2        |                 | 1            | 0               |         |   |   |   |   |
| 6  | 2  | Ben               | 5         |          | 5               |              |                 | 2       |   |   |   |   |
| 7  | 3  | Jane              | 4         | 2        |                 | 2            | 5               | 3       |   |   |   |   |
| 8  | 4  | Guiga             |           | 3        | 3               | 3            | 3               | 4       |   |   |   |   |
| 9  | 5  | Thomas            | 4         | 4        |                 | 4            |                 |         |   |   |   |   |
| 10 | 6  | Marisa            | 4         | 3        | 2               |              |                 | 4       |   |   |   |   |
| 11 | 7  | Lucas             |           | 1        | 0               | 3            | 3               | 2       |   |   |   |   |
| 12 | 8  | Emma              | 4         | 5        | 4               | 5            |                 | 4       |   |   |   |   |
| 13 | 9  | Olivia            | 5         | 2        | 2               | 2            |                 |         |   |   |   |   |
| 14 | 10 | Lewis             | 4         | 3        |                 | 3            |                 | 0       |   |   |   |   |
| 15 |    |                   |           |          |                 |              |                 |         |   |   |   |   |

2. Follow the instructions to populate the input fields, as demonstrated in the figure below, then click OK.

The screenshot shows the Excel interface with the `=knn_nearest` function dialog box open. The dialog box has the following fields:

- Known\_x:** C5:H14
- Reference:** C7:H7
- Normalize:** (empty)
- Dist\_Scale\_Vec:** (empty)

The formula bar shows `=knn_nearest(C5:H14,C7:H7)`. The spreadsheet shows the same data as the previous table, with the formula entered in cell C7. The dialog box also displays the function arguments and the formula result.

3. Remember that this is an array function. Select the column in which you want the output to be displayed: this should be a column of the same length as the number of users. In the figure below, we selected cells K5:K14.

|    |                   |           |           |                            |                 |              |              |           |   |   |   |   |
|----|-------------------|-----------|-----------|----------------------------|-----------------|--------------|--------------|-----------|---|---|---|---|
| K5 |                   | fx        |           | =knn_nearest(C5:H14,C7:H7) |                 |              |              |           |   |   |   |   |
|    | A                 | B         | C         | D                          | E               | F            | G            | H         | I | J | K | L |
| 1  |                   |           |           |                            |                 |              |              |           |   |   |   |   |
| 2  |                   |           |           |                            |                 |              |              |           |   |   |   |   |
| 3  | Movie rating data |           | Movie 1   | Movie 2                    | Movie 3         | Movie 4      | Movie 5      | Movie 6   |   |   |   |   |
| 4  | User number       | User name | Godfather | Top Gun                    | Bourne Identity | Pretty Woman | Working Girl | Moneyball |   |   |   |   |
| 5  | 1                 | Paul      | 5         | 2                          |                 | 1            |              |           |   |   |   |   |
| 6  | 2                 | Ben       | 5         |                            | 5               |              |              | 2         |   |   |   |   |
| 7  | 3                 | Jane      | 4         | 2                          |                 | 2            | 5            | 3         |   |   |   |   |
| 8  | 4                 | Guigal    |           | 3                          | 3               | 3            | 3            | 4         |   |   |   |   |
| 9  | 5                 | Thomas    | 4         | 4                          |                 | 4            |              |           |   |   |   |   |
| 10 | 6                 | Marisa    | 4         | 3                          | 2               |              |              | 4         |   |   |   |   |
| 11 | 7                 | Lucas     |           | 1                          |                 | 3            | 3            | 2         |   |   |   |   |
| 12 | 8                 | Emma      | 4         | 5                          | 4               | 5            |              | 4         |   |   |   |   |
| 13 | 9                 | Olivia    | 5         | 2                          | 2               | 2            |              |           |   |   |   |   |
| 14 | 10                | Lewis     | 4         | 3                          |                 | 3            |              |           |   |   |   |   |
| 15 |                   |           |           |                            |                 |              |              |           |   |   |   |   |

- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the predictions. You can also add a title to the output-column and format the output-cells to display the ranking without any decimals. *Remark: for recent versions of Excel, this step is not necessary.*

|    |                   |           |           |         |                 |              |              |           |   |   |       |   |  |
|----|-------------------|-----------|-----------|---------|-----------------|--------------|--------------|-----------|---|---|-------|---|--|
| K5 |                   |           |           |         |                 |              |              |           |   |   |       |   |  |
|    | A                 | B         | C         | D       | E               | F            | G            | H         | I | J | K     | L |  |
| 2  |                   |           |           |         |                 |              |              |           |   |   |       |   |  |
| 3  | Movie rating data | Movie 1   | Movie 2   | Movie 3 | Movie 4         | Movie 5      | Movie 6      |           |   |   |       |   |  |
| 4  | User number       | User name | Godfather | Top Gun | Bourne Identity | Pretty Woman | Working Girl | Moneyball |   |   |       |   |  |
| 5  | 1                 | Paul      | 5         | 2       |                 | 1            | 0            |           |   |   | 3.00  |   |  |
| 6  | 2                 | Ben       | 5         |         | 5               |              |              | 2         |   |   | 9.00  |   |  |
| 7  | 3                 | Jane      | 4         | 2       |                 | 2            | 5            | 3         |   |   | 6.00  |   |  |
| 8  | 4                 | Guiga     |           | 3       | 3               | 3            | 3            | 4         |   |   | 2.00  |   |  |
| 9  | 5                 | Thomas    | 4         | 4       |                 | 4            |              |           |   |   | 4.00  |   |  |
| 10 | 6                 | Marisa    | 4         | 3       | 2               |              |              | 4         |   |   | 7.00  |   |  |
| 11 | 7                 | Lucas     |           | 1       | 0               | 3            | 3            | 2         |   |   | 5.00  |   |  |
| 12 | 8                 | Emma      | 4         | 5       | 4               | 5            |              | 4         |   |   | 10.00 |   |  |
| 13 | 9                 | Olivia    | 5         | 2       | 2               | 2            |              |           |   |   | 8.00  |   |  |
| 14 | 10                | Lewis     | 4         | 3       |                 | 3            |              | 0         |   |   | 1.00  |   |  |
| 15 |                   |           |           |         |                 |              |              |           |   |   |       |   |  |

To understand the output, consider the first number returned, 3. This means that the closest person to Jane is the 3rd row (i.e., Jane herself). The second number is 9. This means the second closest person is the 9th row (i.e., Olivia).

## 1.6. BA\_RMSE

The example illustrated below is available on the *add-in* webpage by downloading the *Classification, KNN, Misc* file and going to the *ROC\_no\_cost* sheet.

Suppose that you have access to 10 experiments for which you observed **actual outcome** and the **predicted outcome** generated by some predictive model.

| Actual | Predicted |
|--------|-----------|
| 8.0    | 8.3       |
| 9.3    | 9.1       |
| 7.5    | 7.2       |
| 8.9    | 10.0      |
| 10.2   | 10.1      |
| 8.3    | 8.3       |
| 8.8    | 9.0       |
| 8.8    | 8.7       |
| 10.7   | 10.6      |
| 11.7   | 11.2      |

We illustrate in this section a function that computes the Root Mean Square Error.

To use the function:

1. Select the cell in which you want the output to be displayed; call the function by typing `=BA_RMSE(` in the formula bar and then pressing the  $f_x$  symbol next to the formula bar.

SUM    X    ✓     $f_x$     =BA\_RMSE(

|    | A | B                | C    | D | E         | F | G | H | I |
|----|---|------------------|------|---|-----------|---|---|---|---|
| 1  |   |                  |      |   |           |   |   |   |   |
| 2  |   |                  |      |   |           |   |   |   |   |
| 3  |   | Actual Predicted |      |   |           |   |   |   |   |
| 4  |   | 8.0              | 8.3  |   | =BA_RMSE( |   |   |   |   |
| 5  |   | 9.3              | 9.1  |   |           |   |   |   |   |
| 6  |   | 7.5              | 7.2  |   |           |   |   |   |   |
| 7  |   | 8.9              | 10.0 |   |           |   |   |   |   |
| 8  |   | 10.2             | 10.1 |   |           |   |   |   |   |
| 9  |   | 8.3              | 8.3  |   |           |   |   |   |   |
| 10 |   | 8.8              | 9.0  |   |           |   |   |   |   |
| 11 |   | 8.8              | 8.7  |   |           |   |   |   |   |
| 12 |   | 10.7             | 10.6 |   |           |   |   |   |   |
| 13 |   | 11.7             | 11.2 |   |           |   |   |   |   |
| 14 |   |                  |      |   |           |   |   |   |   |
| 15 |   |                  |      |   |           |   |   |   |   |
| 16 |   |                  |      |   |           |   |   |   |   |

2. Follow the instructions to populate the inputs of the function.

A4    X    ✓     $f_x$     =BA\_RMSE(B4:B13,A4:A13)

|    | A | B                | C    | D | E | F | G | H | I | J | K | L | M |
|----|---|------------------|------|---|---|---|---|---|---|---|---|---|---|
| 1  |   |                  |      |   |   |   |   |   |   |   |   |   |   |
| 2  |   |                  |      |   |   |   |   |   |   |   |   |   |   |
| 3  |   | Actual Predicted |      |   |   |   |   |   |   |   |   |   |   |
| 4  |   | 8.0              | 8.3  |   |   |   |   |   |   |   |   |   |   |
| 5  |   | 9.3              | 9.1  |   |   |   |   |   |   |   |   |   |   |
| 6  |   | 7.5              | 7.2  |   |   |   |   |   |   |   |   |   |   |
| 7  |   | 8.9              | 10.0 |   |   |   |   |   |   |   |   |   |   |
| 8  |   | 10.2             | 10.1 |   |   |   |   |   |   |   |   |   |   |
| 9  |   | 8.3              | 8.3  |   |   |   |   |   |   |   |   |   |   |
| 10 |   | 8.8              | 9.0  |   |   |   |   |   |   |   |   |   |   |
| 11 |   | 8.8              | 8.7  |   |   |   |   |   |   |   |   |   |   |
| 12 |   | 10.7             | 10.6 |   |   |   |   |   |   |   |   |   |   |
| 13 |   | 11.7             | 11.2 |   |   |   |   |   |   |   |   |   |   |
| 14 |   |                  |      |   |   |   |   |   |   |   |   |   |   |
| 15 |   |                  |      |   |   |   |   |   |   |   |   |   |   |
| 16 |   |                  |      |   |   |   |   |   |   |   |   |   |   |
| 17 |   |                  |      |   |   |   |   |   |   |   |   |   |   |
| 18 |   |                  |      |   |   |   |   |   |   |   |   |   |   |
| 19 |   |                  |      |   |   |   |   |   |   |   |   |   |   |
| 20 |   |                  |      |   |   |   |   |   |   |   |   |   |   |

Function Arguments

BA\_RMSE

Predicted B4:B13 = {8.3;9.1;7.2;10.1;8.3;9.0;8.7;10.6;11.2}

Actual A4:A13 = {8.0;9.3;7.5;8.9;10.2;8.3;8.8;8.8;10.7;11.7}

NOT\_IMPLEMENTED =

Function to compute the RMSE between predicted and actual values.

Predicted Column containing predictions.

Formula result = 0.418330086

[Help on this function](#)    OK    Cancel

3. Click OK to display the result, in the example we have **RMSE=0.42**.

## 1.7. Classification Functions

In this section we will illustrate a set of functions that you can use to solve classification problems. All the examples will be built upon the following dataset. Suppose that you have access to 17 experiments (e.g. clinical tests, spam/non-spam email classification, etc.) for which you observe the **actual outcome** of the experiment (1 if successful and 0 if not successful) and the **probability of success** generated by some predictive model.

|         | Predicted   |
|---------|-------------|
| Actual  | probability |
| outcome | (score)     |
| 0       | 0.04        |
| 0       | 0.11        |
| 0       | 0.62        |
| 0       | 0.40        |
| 1       | 0.62        |
| 1       | 0.76        |
| 1       | 0.38        |
| 1       | 0.61        |
| 0       | 0.22        |
| 1       | 0.36        |
| 0       | 0.29        |
| 1       | 0.20        |
| 0       | 0.18        |
| 1       | 0.11        |
| 1       | 0.30        |
| 1       | 0.31        |
| 0       | 0.18        |

### 1.7.1. confusionMatrix

*The example illustrated below is available on the add-in webpage by downloading the Classification, KNN, Misc file and going to the ROC\_no\_cost sheet.*

Before illustrating the function, we build a classifier on the above dataset with a classification threshold of 0.6: we predict as successful (1) the experiments that have a probability of success of at least 0.6 and not successful (0) the others.

|         | Predicted   | Classification  |
|---------|-------------|-----------------|
| Actual  | probability | decision        |
| outcome | (score)     | (threshold 0.6) |
| 0       | 0.04        | 0               |
| 0       | 0.11        | 0               |
| 0       | 0.62        | 1               |
| 0       | 0.40        | 0               |
| 1       | 0.62        | 1               |
| 1       | 0.76        | 1               |
| 1       | 0.38        | 0               |
| 1       | 0.61        | 1               |
| 0       | 0.22        | 0               |
| 1       | 0.36        | 0               |
| 0       | 0.29        | 0               |
| 1       | 0.20        | 0               |
| 0       | 0.18        | 0               |
| 1       | 0.11        | 0               |
| 1       | 0.30        | 0               |
| 1       | 0.31        | 0               |
| 0       | 0.18        | 0               |

We will use **confusionMatrix** to compute the Confusion Matrix associated to the above classifier.

To use the function:

1. Select the first cell in which you want the output to be displayed; call the function by typing **=confusionMatrix(** in the formula bar and then pressing the  $f_x$  symbol next to the formula bar.
2. Follow the instructions to populate the input fields, as demonstrated in the figure below, then click OK. (The actual and predicted values must both be binary.)

The screenshot shows an Excel spreadsheet with the following data in columns A, B, and C:

| Actual outcome | Predicted probability (score) | Classification decision (threshold 0.6) |
|----------------|-------------------------------|---|
| 0              | 0.04                          | 0                                       |
| 0              | 0.11                          | 0                                       |
| 0              | 0.62                          | 1                                       |
| 0              | 0.40                          | 0                                       |
| 1              | 0.62                          | 1                                       |
| 1              | 0.76                          | 1                                       |
| 1              | 0.38                          | 0                                       |
| 1              | 0.61                          | 1                                       |
| 0              | 0.22                          | 0                                       |
| 1              | 0.36                          | 0                                       |
| 0              | 0.29                          | 0                                       |
| 1              | 0.20                          | 0                                       |
| 0              | 0.18                          | 0                                       |
| 1              | 0.11                          | 0                                       |
| 1              | 0.30                          | 0                                       |
| 1              | 0.31                          | 0                                       |
| 0              | 0.18                          | 0                                       |

The formula bar shows the function **=confusionMatrix(A6:A22,C6:C22)**. The 'Function Arguments' dialog box is open, showing the 'Actual' range as 'A6:A22' and the 'Prediction' range as 'C6:C22'. The dialog box also shows the resulting confusion matrix and the formula result.

Function Arguments

confusionMatrix

Actual: A6:A22 = {0;0;0;0;1;1;1;0;1;0;1;0;1;1;0}

Prediction: C6:C22 = {0;0;1;0;1;1;0;1;0;0;0;0;0;0;0}

= {"Confusion matrix (5,4)", "Predicted..."}

ARRAY function to compute a confusion matrix from actual and predicted values.

Input:

1. Column of actual values (0 or 1)

2. Column of predicted values (0 or 1)

Output:

1. Confusion matrix of size 5 by 4.

Prediction Predicted values (0 or 1).

Formula result = Confusion matrix (5,4)

Help on this function OK Cancel

- Remember that this is an array function. Select the set of cells in which you want the output to be displayed. In the figure below, we selected cells E3:H7. *Remark: for recent versions of Excel, this step is not necessary.*

|    | A       | B           | C               | D | E                      | F | G | H | I |
|----|---------|-------------|-----------------|---|------------------------|---|---|---|---|
| 1  |         |             |                 |   |                        |   |   |   |   |
| 2  |         |             |                 |   |                        |   |   |   |   |
| 3  |         | Predicted   | Classification  |   | Confusion matrix (5,4) |   |   |   |   |
| 4  | Actual  | probability | decision        |   |                        |   |   |   |   |
| 5  | outcome | (score)     | (threshold 0.6) |   |                        |   |   |   |   |
| 6  | 0       | 0.04        | 0               |   |                        |   |   |   |   |
| 7  | 0       | 0.11        | 0               |   |                        |   |   |   |   |
| 8  | 0       | 0.62        | 1               |   |                        |   |   |   |   |
| 9  | 0       | 0.40        | 0               |   |                        |   |   |   |   |
| 10 | 1       | 0.62        | 1               |   |                        |   |   |   |   |
| 11 | 1       | 0.76        | 1               |   |                        |   |   |   |   |
| 12 | 1       | 0.38        | 0               |   |                        |   |   |   |   |
| 13 | 1       | 0.61        | 1               |   |                        |   |   |   |   |
| 14 | 0       | 0.22        | 0               |   |                        |   |   |   |   |
| 15 | 1       | 0.36        | 0               |   |                        |   |   |   |   |
| 16 | 0       | 0.29        | 0               |   |                        |   |   |   |   |
| 17 | 1       | 0.20        | 0               |   |                        |   |   |   |   |
| 18 | 0       | 0.18        | 0               |   |                        |   |   |   |   |
| 19 | 1       | 0.11        | 0               |   |                        |   |   |   |   |
| 20 | 1       | 0.30        | 0               |   |                        |   |   |   |   |
| 21 | 1       | 0.31        | 0               |   |                        |   |   |   |   |
| 22 | 0       | 0.18        | 0               |   |                        |   |   |   |   |
| 23 |         |             |                 |   |                        |   |   |   |   |

- Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the output. You can also format the output-cells to display the labels of the matrix in boldface.

|                               |          |                  |          |              |
|-------------------------------|----------|------------------|----------|--------------|
| <b>Confusion matrix (5,4)</b> |          | <b>Predicted</b> |          |              |
| <b>Actual</b>                 |          | <b>1</b>         | <b>0</b> | <b>Total</b> |
|                               | <b>1</b> | 3                | 6        | 9            |
|                               | <b>0</b> | 1                | 7        | 8            |
| <b>Total</b>                  |          | 4                | 13       | 17           |

## 1.7.2. ROC

The example illustrated below is available on the *add-in* webpage by downloading the *Classification, KNN, Misc* file and going to the *ROC\_no\_cost* sheet.

An important measure for evaluating the performance of a given classification model is the error rate. For example, consider the confusion matrix calculated in the previous section: the classifier built using a threshold of 0.6 has a *false positive rate* of  $1/8 = 12.5\%$  and a *true positive rate* of  $3/9 = 33.3\%$ . The ROC curve is simply a plot of the true positive versus the false positive rate for different thresholds. Note that, in principle, one can use any score for classification purposes. In the example, the score used was the predicted probability, but any other score can be used as well. By varying the classification threshold, different (FPR, TPR) pairs result, and the ROC curve captures all possible achievable pairs using that particular score/classifier. The ROC curve is a useful tool when you are trying to decide which classification threshold you should select.

To use the function:

0. Insert in a column the list of threshold values you want to test.

| Probability | False    | True     |
|-------------|----------|----------|
| threshold   | positive | positive |
| 0.0         |          |          |
| 0.1         |          |          |
| 0.2         |          |          |
| 0.3         |          |          |
| 0.4         |          |          |
| 0.5         |          |          |
| 0.6         |          |          |
| 0.7         |          |          |
| 0.8         |          |          |
| 0.9         |          |          |
| 1.0         |          |          |

1. Select the cell immediately to the right of the first threshold value, and call the function by typing `=ROC(` in the formula bar and then pressing the  $f_x$  symbol next to the formula bar.
2. Follow the instructions to populate the input fields, as demonstrated in the figure below, then click OK. (For the ROC curve with “Cost” see section 1.7.4 below.)

The screenshot shows an Excel spreadsheet with the following data:

| Actual outcome | Predicted probability (score) | Probability threshold |
|----------------|-------------------------------|-----------------------|
| 0              | 0.04                          | 0.0                   |
| 0              | 0.11                          | 0.1                   |
| 0              | 0.62                          | 0.2                   |
| 0              | 0.40                          | 0.3                   |
| 1              | 0.62                          | 0.4                   |
| 1              | 0.76                          | 0.5                   |
| 1              | 0.38                          | 0.6                   |
| 1              | 0.61                          | 0.7                   |
| 0              | 0.22                          | 0.8                   |
| 1              | 0.36                          | 0.9                   |
| 0              | 0.29                          | 1.0                   |
| 1              | 0.20                          |                       |
| 0              | 0.18                          |                       |
| 1              | 0.11                          |                       |
| 1              | 0.30                          |                       |
| 1              | 0.31                          |                       |
| 0              | 0.18                          |                       |

The dialog box for the `ROC` function is open, showing the following arguments:

- Score:** B6:B22
- Actual:** A6:A22
- Threshold:** D6:D16
- Cost:**
- Reversed:**

The formula result is 1.

3. Remember that this is an array function. Select the set of cells in which you want the output to be displayed.

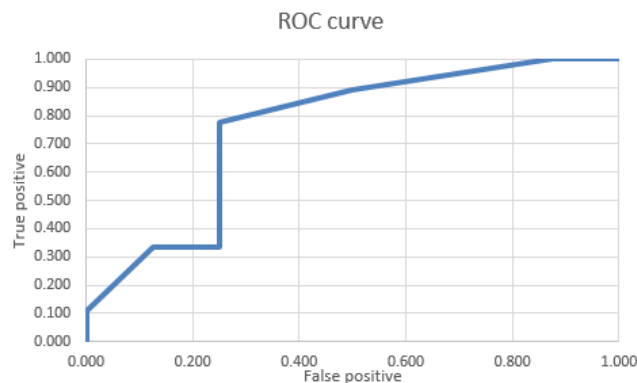


| Probability | False    | True     |
|-------------|----------|----------|
| threshold   | positive | positive |
| 0.0         | 1.000    |          |
| 0.1         |          |          |
| 0.2         |          |          |
| 0.3         |          |          |
| 0.4         |          |          |
| 0.5         |          |          |
| 0.6         |          |          |
| 0.7         |          |          |
| 0.8         |          |          |
| 0.9         |          |          |
| 1.0         |          |          |

4. Position the cursor in the formula bar, and press **Ctrl+Shift+Enter** to display the output. You can also format the output-cells to display only three decimals. *Remark: for recent versions of Excel, this step is not necessary.*

| Probability | False    | True     |
|-------------|----------|----------|
| threshold   | positive | positive |
| 0.0         | 1.000    | 1.000    |
| 0.1         | 0.875    | 1.000    |
| 0.2         | 0.500    | 0.889    |
| 0.3         | 0.250    | 0.778    |
| 0.4         | 0.250    | 0.333    |
| 0.5         | 0.125    | 0.333    |
| 0.6         | 0.125    | 0.333    |
| 0.7         | 0.000    | 0.111    |
| 0.8         | 0.000    | 0.000    |
| 0.9         | 0.000    | 0.000    |
| 1.0         | 0.000    | 0.000    |

5. You can easily plot the false positive and true positive rates to display the ROC curve. To generate the graph below: select the set of cells that display the output of the **ROC** function; then select **INSERT - Charts - Scatter - Scatter with straight lines**.



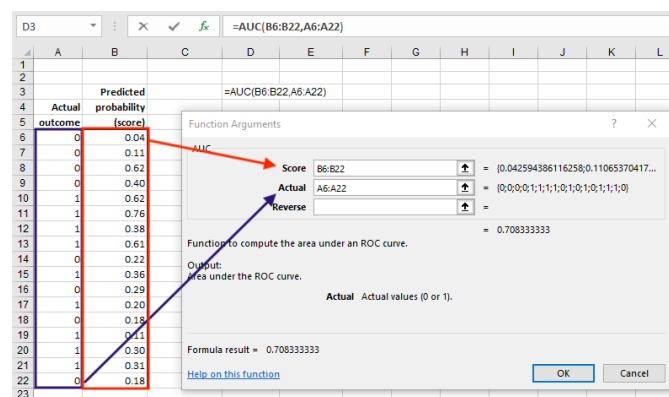
### 1.7.3. AUC

The example illustrated below is available on the add-in webpage by downloading the Classification, KNN, Misc file and going to the ROC\_no\_cost sheet.

This function computes the area under the ROC curve.

To use the function:

1. Select the cell in which you want the output to be displayed; call the function by typing `=AUC(` in the formula bar and then pressing the  $f_x$  symbol next to the formula bar.
2. Follow the instructions to populate the inputs of the function.



3. Click OK to display the result, in the example we have **AUC=0.71**.

### 1.7.4. ROC (with cost information)

The example illustrated below is available on the add-in webpage by downloading the Classification, KNN, Misc file and going to the ROC\_with\_cost sheet.

This is a variation on the basic **ROC** function, when you have a cost associated to each type of classification error. The costs must be expressed in terms of a cost matrix.

|    | A       | B           | C | D           | E        | F        | G     | H | I           | J         | K  |
|----|---------|-------------|---|-------------|----------|----------|-------|---|-------------|-----------|----|
| 1  |         |             |   |             |          |          |       |   |             |           |    |
| 2  |         |             |   |             |          |          |       |   |             |           |    |
| 3  |         | Predicted   |   |             |          |          |       |   |             |           |    |
| 4  | Actual  | probability |   | Probability | False    | True     | Total |   | Cost matrix | Predicted |    |
| 5  | outcome | (score)     |   | threshold   | positive | positive | Cost  |   | Actual      | 1         | 0  |
| 6  | 0       | 0.04        |   | 0.0         |          |          |       |   | 1           | 6         | 10 |
| 7  | 0       | 0.11        |   | 0.1         |          |          |       |   | 0           | 3         | 0  |
| 8  | 0       | 0.62        |   | 0.2         |          |          |       |   |             |           |    |
| 9  | 0       | 0.40        |   | 0.3         |          |          |       |   |             |           |    |
| 10 | 1       | 0.62        |   | 0.4         |          |          |       |   |             |           |    |
| 11 | 1       | 0.76        |   | 0.5         |          |          |       |   |             |           |    |
| 12 | 1       | 0.38        |   | 0.6         |          |          |       |   |             |           |    |
| 13 | 1       | 0.61        |   | 0.7         |          |          |       |   |             |           |    |
| 14 | 0       | 0.22        |   | 0.8         |          |          |       |   |             |           |    |
| 15 | 1       | 0.36        |   | 0.9         |          |          |       |   |             |           |    |
| 16 | 0       | 0.29        |   | 1.0         |          |          |       |   |             |           |    |
| 17 | 1       | 0.20        |   |             |          |          |       |   |             |           |    |
| 18 | 0       | 0.18        |   |             |          |          |       |   |             |           |    |
| 19 | 1       | 0.11        |   |             |          |          |       |   |             |           |    |
| 20 | 1       | 0.30        |   |             |          |          |       |   |             |           |    |
| 21 | 1       | 0.31        |   |             |          |          |       |   |             |           |    |
| 22 | 0       | 0.18        |   |             |          |          |       |   |             |           |    |

To use the function follow the same steps as the basic **ROC** function, with the following variations:

- At *Step 2*. insert also the cost matrix information: type J6:K7 in the **Cost** input field.
- At *Step 3*. select three columns, as the function now outputs also the total cost.  
*Remark: for recent versions of Excel, this step is not necessary.*

| Probability | False    | True     | Total |
|-------------|----------|----------|-------|
| threshold   | positive | positive | Cost  |
| 0.0         | 1.000    |          |       |
| 0.1         |          |          |       |
| 0.2         |          |          |       |
| 0.3         |          |          |       |
| 0.4         |          |          |       |
| 0.5         |          |          |       |
| 0.6         |          |          |       |
| 0.7         |          |          |       |
| 0.8         |          |          |       |
| 0.9         |          |          |       |
| 1.0         |          |          |       |

## 1.8. Monte Carlo Simulation

In this section we will illustrate how to run a Monte Carlo Simulation in a spreadsheet.

*The example illustrated below is available on the add-in webpage by downloading the Monte Carlo Simulation file and going to the MCSim sheet.*

**Example: simple revenue simulation.** Suppose that you have 100 customers coming into your shop on each day and that each customer purchases something with probability 40%. The accrued revenue per purchase is normally distributed with a mean of \$20 and a

standard deviation of \$5. Simulate the **number of purchases**, the **revenue per purchase**, and the **total revenues**. Run the simulation for 500 trials.

To set up the simulation:

S0. Populate the spreadsheet with the given data.

|    | A                               | B   | C                 | D   | E | F |
|----|---------------------------------|-----|-------------------|-----|---|---|
| 1  |                                 |     |                   |     |   |   |
| 2  |                                 |     |                   |     |   |   |
| 3  |                                 |     |                   |     |   |   |
| 4  | Simple revenue simulation       |     |                   |     |   |   |
| 5  | Number of customers             | 100 |                   |     |   |   |
| 6  | Probability of purchase         | 40% | Simulation trials | 500 |   |   |
| 7  | Number of purchases (binomial)  |     |                   |     |   |   |
| 8  |                                 |     |                   |     |   |   |
| 9  | Mean revenue per purchase       | 20  |                   |     |   |   |
| 10 | Std dev of revenue per purchase | 5   |                   |     |   |   |
| 11 | Revenue per purchase (normal)   |     |                   |     |   |   |
| 12 |                                 |     |                   |     |   |   |
| 13 | Total revenue                   |     |                   |     |   |   |
| 14 |                                 |     |                   |     |   |   |

S1. Insert the formulas for the quantities you want to simulate.

(S1.i) Number of purchases: this is a random sample from a Binomial distribution with 100 trials and probability equal to 0.4. You can use the add-in function **BinomSim** to generate this number.

The screenshot shows the Excel interface with the **BinomSim** function dialog box open. The dialog box has the following details:

- Function:** BinomSim
- Arguments:**
  - N:** B5 = 100
  - P:** B6 = 0.4
- Formula result:** 44
- Description:** Randomly sample from binomial distribution with the number of trials n and the success probability p. P is a success probability in each trial.

The background spreadsheet shows the following data:

|    | A                               | B                | C                 | D   | E | F |
|----|---------------------------------|------------------|-------------------|-----|---|---|
| 1  |                                 |                  |                   |     |   |   |
| 2  |                                 |                  |                   |     |   |   |
| 3  |                                 |                  |                   |     |   |   |
| 4  | Simple revenue simulation       |                  |                   |     |   |   |
| 5  | Number of customers             | 100              |                   |     |   |   |
| 6  | Probability of purchase         | 40%              | Simulation trials | 500 |   |   |
| 7  | Number of purchases (binomial)  | =BinomSim(B5,B6) |                   |     |   |   |
| 8  |                                 |                  |                   |     |   |   |
| 9  | Mean revenue per purchase       | 20               |                   |     |   |   |
| 10 | Std dev of revenue per purchase | 5                |                   |     |   |   |
| 11 | Revenue per purchase (normal)   |                  |                   |     |   |   |
| 12 |                                 |                  |                   |     |   |   |
| 13 | Total revenue                   |                  |                   |     |   |   |

(S1.ii) Revenue per purchase: this is a random sample from a Normal distribution with mean 20 and standard deviation 5. You can use the add-in function **NormalSim** to generate this number.

The screenshot shows the Excel interface with the **NormalSim** function dialog box open. The dialog box has the following details:

- Function:** NormalSim
- Arguments:**
  - Mean:** B9 = 20
  - Standard\_dev:** B10 = 5
- Formula result:** 22.3
- Description:** Randomly sample from normal distribution with specified mean and standard\_dev. Standard\_dev is the standard deviation of the distribution, a positive number.

The background spreadsheet shows the following data:

|    | A                               | B                  | C | D | E | F | G | H | I | J |
|----|---------------------------------|--------------------|---|---|---|---|---|---|---|---|
| 1  |                                 |                    |   |   |   |   |   |   |   |   |
| 2  |                                 |                    |   |   |   |   |   |   |   |   |
| 3  |                                 |                    |   |   |   |   |   |   |   |   |
| 4  | Simple revenue simulation       |                    |   |   |   |   |   |   |   |   |
| 5  | Number of customers             | 100                |   |   |   |   |   |   |   |   |
| 6  | Probability of purchase         | 40%                |   |   |   |   |   |   |   |   |
| 7  | Number of purchases (binomial)  | 32                 |   |   |   |   |   |   |   |   |
| 8  |                                 |                    |   |   |   |   |   |   |   |   |
| 9  | Mean revenue per purchase       | 20                 |   |   |   |   |   |   |   |   |
| 10 | Std dev of revenue per purchase | 5                  |   |   |   |   |   |   |   |   |
| 11 | Revenue per purchase (normal)   | =NormalSim(B9,B10) |   |   |   |   |   |   |   |   |
| 12 |                                 |                    |   |   |   |   |   |   |   |   |
| 13 | Total revenue                   |                    |   |   |   |   |   |   |   |   |

(S1.ii) Total Revenues: this is simply the product of number of purchases times revenue per purchase. Select cell B13 and insert the formula =B7\*B11.

S2. Create the formula row, which will be your input for the simulation. Simply copy and paste the formulas from (1.i), (1.ii) and (1.iii) to an empty row. We did this in the figure below, in particular we inserted =B7 in cell E5, =B11 in cell F5, and =B13 in cell G5.

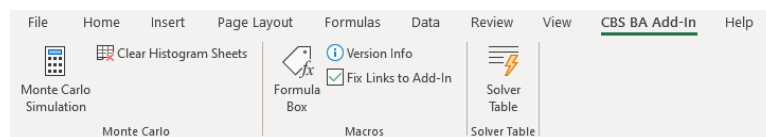
|    |                                 |       |   |                   |              |                  |           |   |  |
|----|---------------------------------|-------|---|-------------------|--------------|------------------|-----------|---|--|
| E5 | :                               |       |   |                   | =B7          |                  |           |   |  |
|    | A                               | B     | C | D                 | E            | F                | G         | H |  |
| 1  |                                 |       |   |                   |              |                  |           |   |  |
| 2  |                                 |       |   |                   |              |                  |           |   |  |
| 3  |                                 |       |   |                   |              |                  |           |   |  |
| 4  | Simple revenue simulation       |       |   |                   | Num purchase | Rev per purchase | Total rev |   |  |
| 5  | Number of customers             | 100   |   | Formula           | 32           | 21.8             | 698.9     |   |  |
| 6  | Probability of purchase         | 40%   |   | Simulation trials | 500          |                  |           |   |  |
| 7  | Number of purchases (binomial)  | 32    |   |                   |              |                  |           |   |  |
| 8  |                                 |       |   |                   |              |                  |           |   |  |
| 9  | Mean revenue per purchase       | 20    |   |                   |              |                  |           |   |  |
| 10 | Std dev of revenue per purchase | 5     |   |                   |              |                  |           |   |  |
| 11 | Revenue per purchase (normal)   | 21.8  |   |                   |              |                  |           |   |  |
| 12 |                                 |       |   |                   |              |                  |           |   |  |
| 13 | Total revenue                   | 698.9 |   |                   |              |                  |           |   |  |
| 14 |                                 |       |   |                   |              |                  |           |   |  |

S3. You can also add an (optional) row of labels which indicates the variable for which you would like an histogram to be automatically generated, along with the simulation results. In our example we insert a row of labels with 0s for the first two variables and 1 for **total revenues**. As a result an histogram for this last variable will be generated, along with the simulation results.

|  |                   |              |                  |           |
|--|-------------------|--------------|------------------|-----------|
|  |                   | Num purchase | Rev per purchase | Total rev |
|  | Formula           | 32           | 21.8             | 698.9     |
|  | Simulation trials | 500          |                  |           |

To run the simulation:

R0. Go to the CBS BA ADD-IN tab and then select the Monte Carlo Simulation to pop up the MonteCarlo Simulation Dialog. (Alternatively, the dialog can be popped up by clicking Ctrl+Shift+M.)



R1. Populate the inputs of the function in the Dialog Box and then click OK. Also, by selecting the **Print Histogram** check box you can automatically generate histograms of the selected variables. Note that the simulation can track any number of variables in a single row, not just the three used in this example.

MonteCarlo Simulation Setup

### Monte-Carlo Simulation Tool

Where is/are the formula(s) for the quantity(ies) you would like to simulate?

Check this box to print histograms summarizing the results of this simulation  
☒

Optionally, you may select a range of 0/1 values in which each entry corresponds to one variable you are simulating; histograms will only be output for variables containing a 1

How many simulation trials would you like to run? Select a cell containing the number, or enter the number here

Where would you like to output the result? Select the cell at the top-left corner of the desired output range

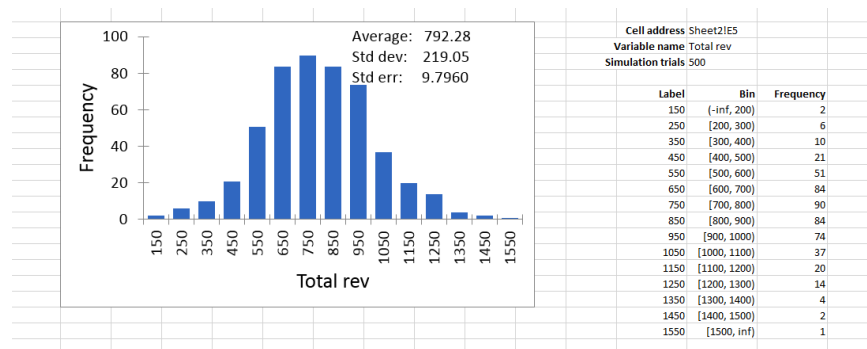
Important note: running this tool while other Excel workbooks are open can cause significant lags in performance. We recommend closing all other workbooks before clicking run below.

**Run the Simulation**

You can format the output of the simulation to display nicely as in the figure below.

|                                  |       |                    |                  |
|----------------------------------|-------|--------------------|------------------|
| <b>Simple revenue simulation</b> |       |                    |                  |
| Number of customers              | 100   | Num purchase       | Rev per purchase |
| Probability of purchase          | 40%   | Formula            | 39               |
| Number of purchases (binomial)   | 39    | Simulation trials  | 1000             |
| Mean revenue per purchase        | 20    | CPU seconds        | 1.349609375      |
| Std dev of revenue per purchase  | 5     |                    |                  |
| Revenue per purchase (normal)    | 24.4  |                    |                  |
| Total revenue                    | 950.4 |                    |                  |
|                                  |       | Average            | 40.036           |
|                                  |       | Standard deviation | 4.881            |
|                                  |       | Standard error     | 0.154            |
|                                  |       | Minimum            | 25               |
|                                  |       | Maximum            | 57               |
|                                  |       | Percentiles        |                  |
|                                  |       | 0.01               | 28               |
|                                  |       | 0.05               | 32               |
|                                  |       | 0.1                | 34               |
|                                  |       | 0.5                | 40               |
|                                  |       | 0.9                | 46               |
|                                  |       | 0.95               | 48               |
|                                  |       | 0.99               | 52               |

In separate sheets the macro outputs the histograms. As an example, we present the histogram of **total revenues**.



You can use CBS BA Add-In | Clear histogram sheets to clear previously created histogram sheets.