# The Exponential Smoothing Macro (ESM) for Time Series Forecasting

# Operations Manual

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## Foreword

This macro was developed, under the auspices of the Lancaster Centre for Forecasting and our supervision, by Mr. Young Ho Seo. The program is available to users of the book via the website. Instructors should go to www.Wessexlearning.com/pobf2e and students should go to www.Wessexlearning.org/pobf2e .

# 1. Objective of Exponential Smoothing Macro (ESM)

The detailed calculations underlying exponential smoothing methods of forecasting are usually "hidden" from the user in commercial software packages. Seeing such complex calculations may not be important to the industrial user provided the forecasting software has been comprehensively tested to ensure reliability. However, for educational purposes it is instructive to see both the end results and how the methods work. The Exponential Smoothing Macro (ESM) presents a range of exponential smoothing methods in an understandable form in a way that makes the forecasting process visible to the user. Each step of the calculation leading to the forecast values is readily traceable. The ESM may also be used to demonstrate the evaluation of a forecasting method using the concept of a *rolling origin*. The rolling origin demonstration should increase users' ability to evaluate the accuracy of forecasting methods.

# 2. Functionality of Exponential Smoothing Macro

The Exponential Smoothing Macro was designed primarily as an educational tool for time series forecasting. Execution tends to be slow for long series, but for a typical PC or laptop, the performance is typically acceptable for series with 300 or fewer observations. The macro is capable of generating forecasts using any of nine different exponential smoothing methods, listed below. The macro generates the forecasting equations in either an error correction version or a non-error correction version in the spreadsheet.

The nine time series forecasting methods include:

- Single exponential smoothing (SES)
- Additive seasonal exponential smoothing (ASES)
- Multiplicative seasonal exponential smoothing (MSES)
- Additive trend exponential smoothing (ATES; Holt's method)
- Damped additive trend exponential smoothing (DATES)
- Additive trend additive seasonal exponential smoothing (ATASES; Additive Holt-Winters' method))
- Additive trend multiplicative seasonal exponential smoothing (ATMSES; Multiplicative Holt-Winters' method)
- Damped additive trend additive seasonal exponential smoothing (DATASES)
- Damped additive trend multiplicative seasonal exponential smoothing (DATMSES).

The seasonal methods are designed to forecast a series with quarterly (seasonal cycle = 4), monthly (seasonal cycle = 12) or any other seasonal cycle of integer length. Logarithmic and Box-Cox transformations may be performed as an integrated step in the forecasting process. The ESM also provides a demonstration of the use of a rolling origin to evaluate forecasting performance, for both the single exponential smoothing and linear trend exponential smoothing methods. Finally the macro provides a procedure for a preliminary seasonality check.

# 3. Requirements for running the ESM

## 3.1 Using MS-Excel 2007

The ESM was created using MS-Excel 2007. Therefore, the ESM will perform the best in the MS-Excel 2007 environment but may also work in previous versions of MS-Excel. To run the macro, Solver must be preinstalled in MS-Excel. If not, please follow the steps below:

- Go to “Excel Options” and click “Add-Ins”
- Click the “Go” button right next to the “Manage” label (make sure “Excel Add-Ins” is selected before you click the “Go” button)
- In the “Add-Ins” pop up window, check the box for the “Solver Add-In”
- If the “Solver Add-In” is successfully installed, then you should be able to see “Solver” in the analysis section under “Data” tab

## 3.2 Using MS-Excel 2010

To preinstall Solver, proceed as follows:

- Click on “File” and select “Options”
- In “Excel Options” click “Add-Ins”
- Click the “Go” button right next to the “Manage” label (make sure “Excel Add-Ins” is selected before you click the “Go” button)
- In the “Add-Ins” pop up window, check the box for the “Solver Add-In”
- If the “Solver Add-In” is successfully installed, then you should be able to see “Solver” in the analysis section under “Data” tab

## 3.3 VBA requirements to run the ESM

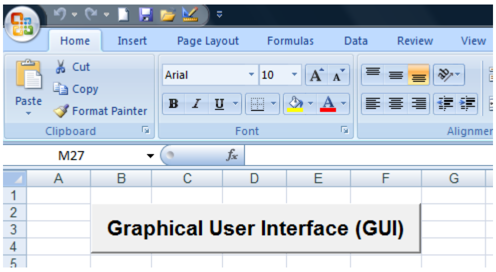
Six VBA references are used for the macro:

- Visual basic for applications
- Microsoft Excel 12.0 Object library
- OLE automation
- Microsoft Office 12.0 Object library
- Solver
- Microsoft Forms 2.0 Object library

# 4. How to use the Exponential Smoothing Macro

## 4.1 Introduction to the Graphical User Interface (GUI)

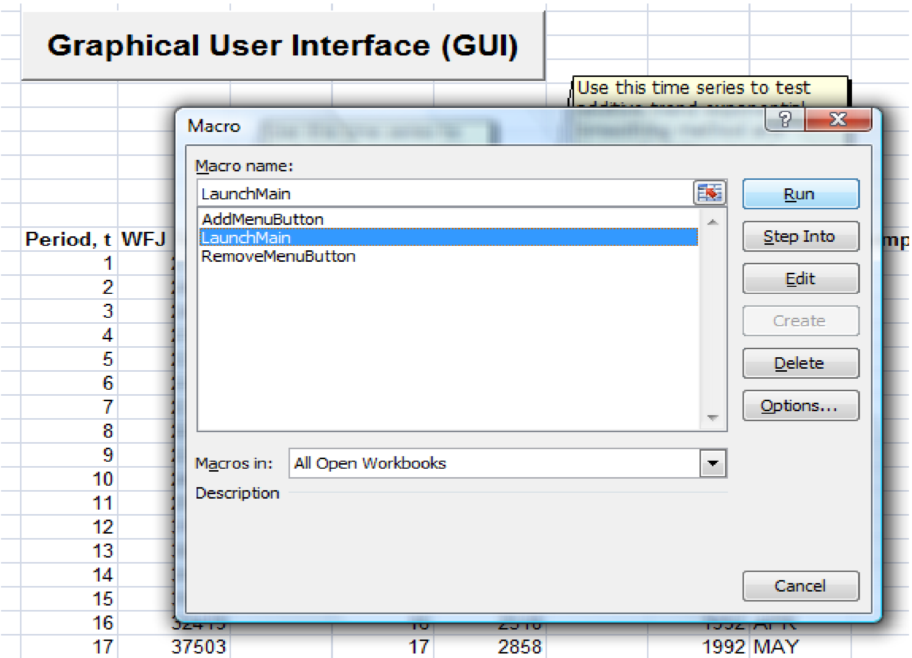
The Graphical User Interface (GUI) is provided to access all the macros in the ESM. Therefore, users without any knowledge of macro programming can make full use of the ESM. The GUI can be called by clicking the gray button called "Graphical User Interface (GUI)" in the "Exponential Smoothing Macro" sheet (Screenshot 1).




**Screenshot 1**

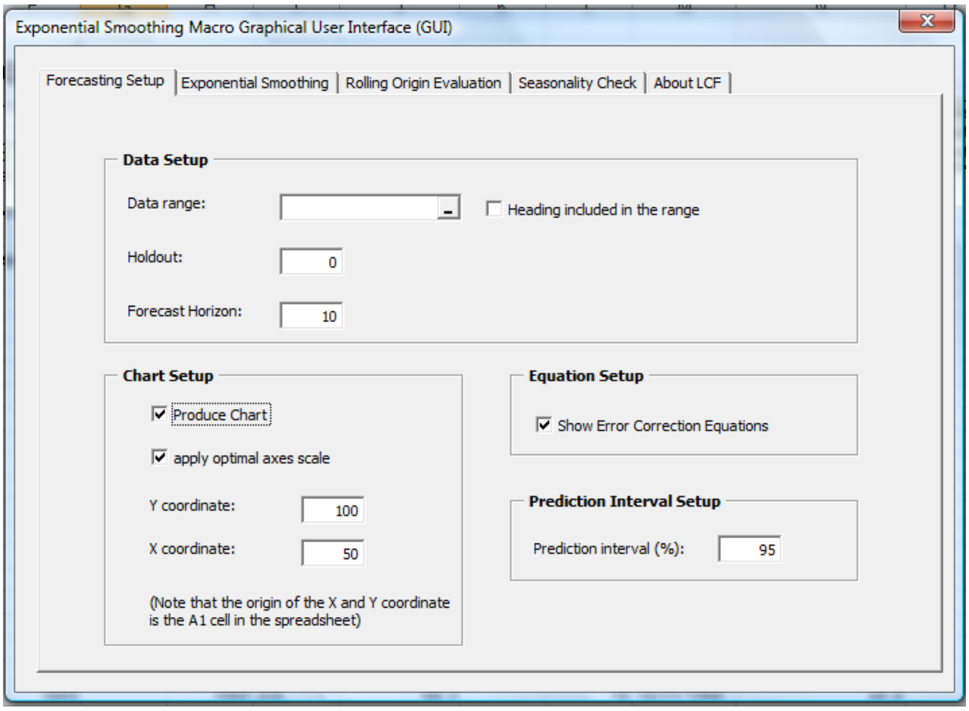
An alternative way to call the GUI is to execute the "LaunchMain" macro using M-Excel's built-in Macro Execution window (Screenshot 2). The steps are:

- Click the "Developer" tab
- Click the "Macros" button in the "Code" section
- When the Macro Execution window pops up, select the "LaunchMain" macro
- Hit the "Run" button




**Screenshot 2**

The GUI consists of 5 tabs (Screenshot 3).




**Screenshot 3**

Brief descriptions for each tab are given below:

- “Forecasting Setup” tab –use this tab to load the time series data, define the set-up for charts, and to select a format for writing out the forecast function.

- “Exponential smoothing” tab - controls the model settings for the nine exponential smoothing methods as well as the logarithmic and Box-Cox transformations.

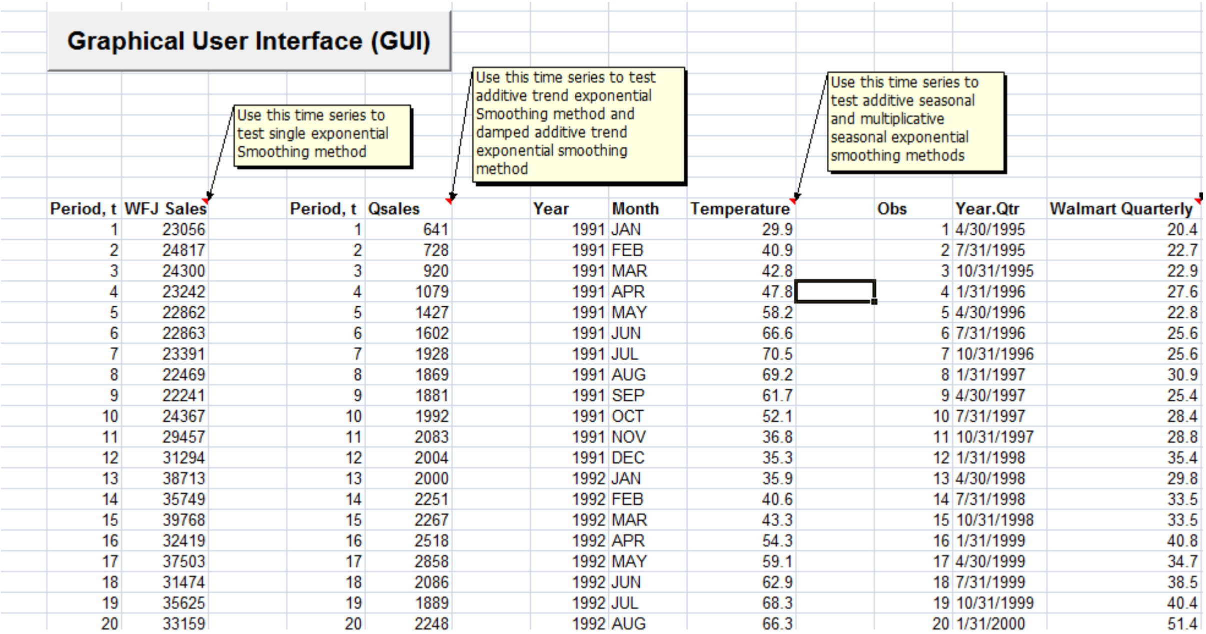
- “Rolling Origin Evaluation” tab – provides a demonstration of the rolling origin evaluation approach using single exponential smoothing (SES) and additive trend exponential smoothing (ATES).

- “Seasonality Check” tab – provides a means of inspecting seasonality graphically.

- “About LCF” tab – provides general information about the Lancaster Centre for Forecasting (LCF).

## 4.2 Time series data

The forecasting model is developed using time series data. For example, the data might relate to the sales history of a product, daily closing prices of a major stock, macroeconomic series such as quarterly GDP, electricity consumption (often recoded at 15-minute intervals) or annual rainfall. The Exponential Smoothing Macro workbook contains four sample time series so that the user can experiment with different forecasting methods (Screenshot 4).





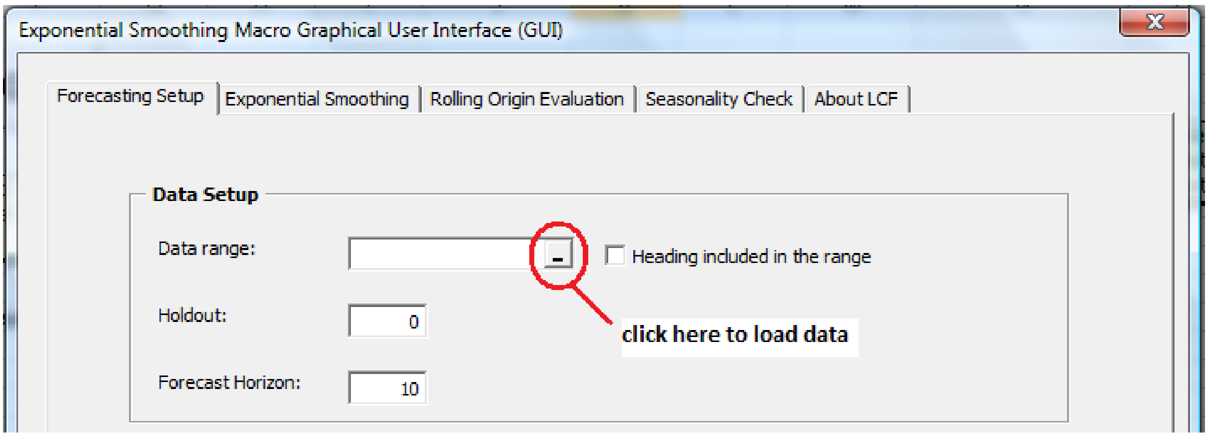
| Period, t | WFJ Sales | Period, t | Qsales | Year | Month | Temperature | Obs | Year.Qtr | Walmart Quarterly |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23056 | 1 | 641 | 1991 | JAN | 29.9 | 1 | 4/30/1995 | 20.4 |
| 2 | 24817 | 2 | 728 | 1991 | FEB | 40.9 | 2 | 7/31/1995 | 22.7 |
| 3 | 24300 | 3 | 920 | 1991 | MAR | 42.8 | 3 | 10/31/1995 | 22.9 |
| 4 | 23242 | 4 | 1079 | 1991 | APR | 47.8 | 4 | 1/31/1996 | 27.6 |
| 5 | 22862 | 5 | 1427 | 1991 | MAY | 58.2 | 5 | 4/30/1996 | 22.8 |
| 6 | 22863 | 6 | 1602 | 1991 | JUN | 66.6 | 6 | 7/31/1996 | 25.6 |
| 7 | 23391 | 7 | 1928 | 1991 | JUL | 70.5 | 7 | 10/31/1996 | 25.6 |
| 8 | 22469 | 8 | 1869 | 1991 | AUG | 69.2 | 8 | 1/31/1997 | 30.9 |
| 9 | 22241 | 9 | 1881 | 1991 | SEP | 61.7 | 9 | 4/30/1997 | 25.4 |
| 10 | 24367 | 10 | 1992 | 1991 | OCT | 52.1 | 10 | 7/31/1997 | 28.4 |
| 11 | 29457 | 11 | 2083 | 1991 | NOV | 36.8 | 11 | 10/31/1997 | 28.8 |
| 12 | 31294 | 12 | 2004 | 1991 | DEC | 35.3 | 12 | 1/31/1998 | 35.4 |
| 13 | 38713 | 13 | 2000 | 1992 | JAN | 35.9 | 13 | 4/30/1998 | 29.8 |
| 14 | 35749 | 14 | 2251 | 1992 | FEB | 40.6 | 14 | 7/31/1998 | 33.5 |
| 15 | 39768 | 15 | 2267 | 1992 | MAR | 43.3 | 15 | 10/31/1998 | 33.5 |
| 16 | 32419 | 16 | 2518 | 1992 | APR | 54.3 | 16 | 1/31/1999 | 40.8 |
| 17 | 37503 | 17 | 2858 | 1992 | MAY | 59.1 | 17 | 4/30/1999 | 34.7 |
| 18 | 31474 | 18 | 2086 | 1992 | JUN | 62.9 | 18 | 7/31/1999 | 38.5 |
| 19 | 35625 | 19 | 1889 | 1992 | JUL | 68.3 | 19 | 10/31/1999 | 40.4 |
| 20 | 33159 | 20 | 2248 | 1992 | AUG | 66.3 | 20 | 1/31/2000 | 51.4 |

**Screenshot 4**

### 4.3 Generating the forecasts

In order to generate the forecasts, proceed as follows:

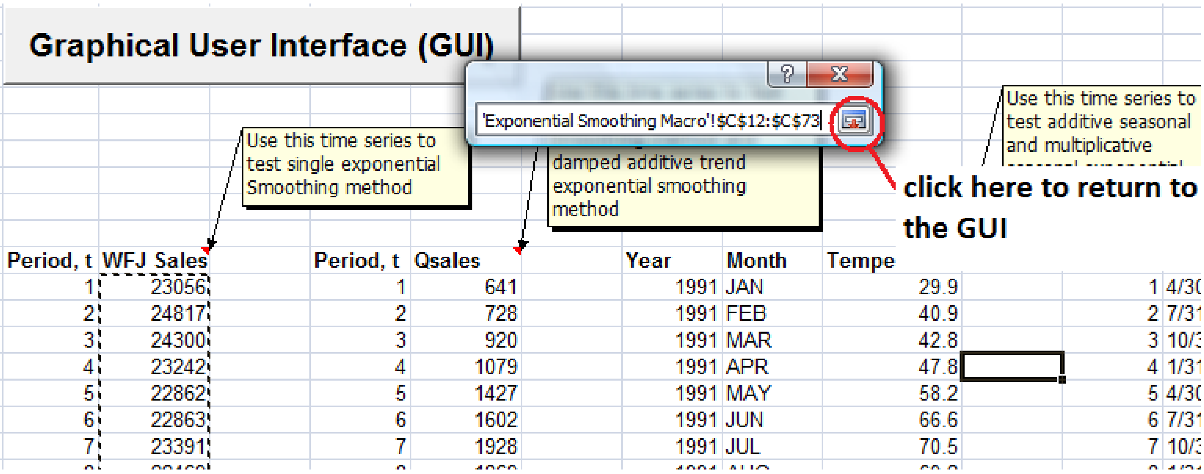
1. Copy the data sets(s) of interest into the ESM; any columns will do including overwriting the sample data sets already included.
2. Load time series data in the “Load data” tab – click the small button with the underscore at the right of the box (Screenshot 5)





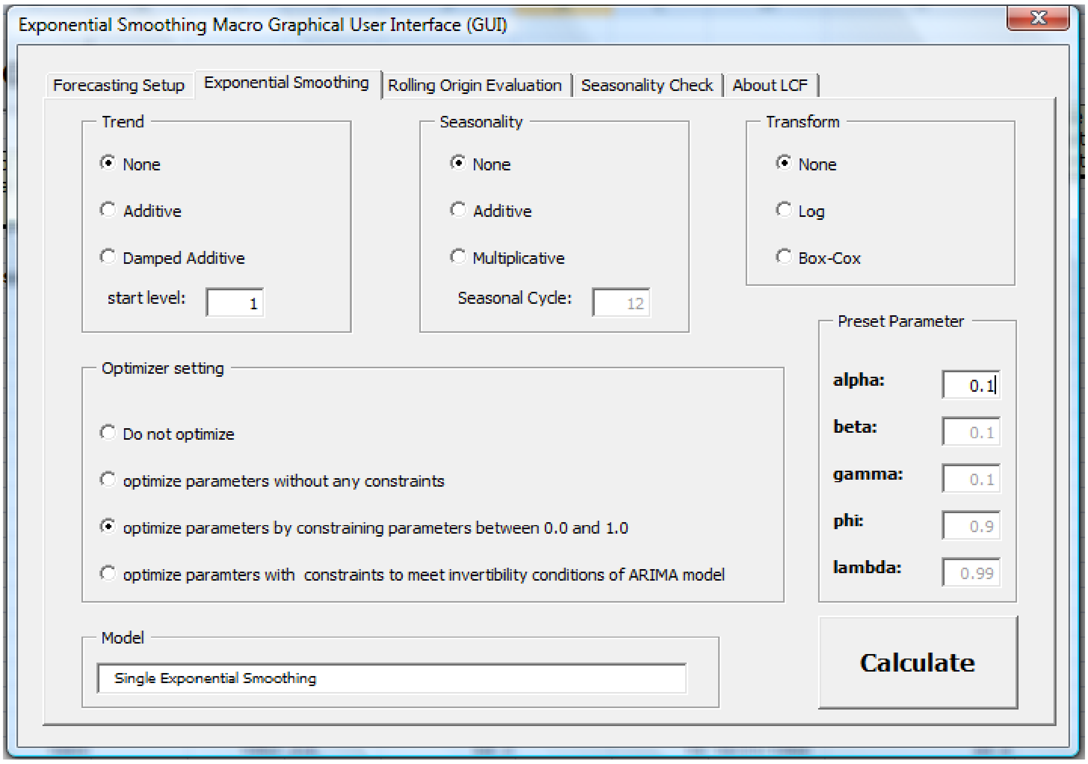
**Screenshot 5**

3. This step returns you to the GUI. Hold the left mouse button down and scroll down the dataset of interest. The selected values are recorded in the pop-up box as shown in Screenshot 6. When the full data set has been identified, click on the icon on the right-hand side of the pop-up box. This action will return you to the "Forecasting Setup" screen.




**Screenshot 6**

4. Check the box for the heading if it is included in the range. Specify the size of the holdout sample for out-of-sample validation. Set the forecasting horizon in the "Forecasting Setup" tab.
5. Keep the check mark in the Chart Setup box if a plot of the actual and forecast values is required. The default settings for the Y and X coordinates will usually be adequate; if not try alternative settings.
6. The forecasts may be generated using either the error correction forms of the updating equations or the non-error correction forms [see the text, pp. 78-79]. The output is unaffected, but clicking on any of the forecast or state variable cells will show the appropriate form of the updating equation.
7. Select the "Exponential Smoothing" tab (Screenshot 7).
8. Specify the desired forecasting method by choosing the appropriate trend and seasonality. The selected model will always be displayed in the text box on the bottom of the screen.




**Screenshot 7**

8A. If the SES method is selected (Trend = None, Seasonality = None), the starting value may be specified as the average of the first *k* observations (default *k*=1).

8B. For any methods with seasonality, the seasonal cycle must be specified (12 for monthly data, 4 for quarterly data, or as appropriate).

9. To apply a transformation, use the “Transform” box under the “Exponential Smoothing” tab to select either the logarithmic (log) or Box-Cox (C-transform) transformation. See Screenshot 7.

10. Either use the default values or specify initial values for the smoothing parameters.

11. If the parameter values are unknown, use the automatic parameter search option by choosing the appropriate optimization option in the optimizer setting. If the “Do not optimize” option is chosen, the initial parameter values will be used to generate the forecasts.

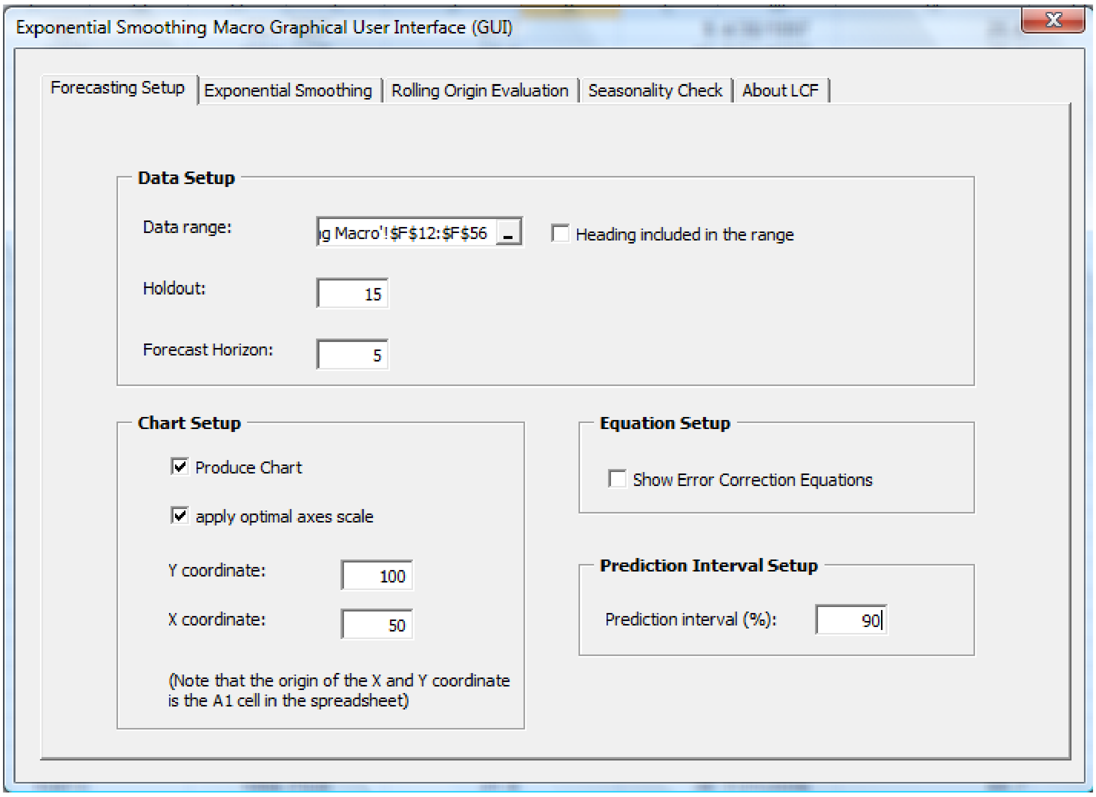
12. Hit the “Calculate” button to compute the forecasts.

13. To compute a new set of forecasts, specify the new forecasting method (if necessary), reset the various options and hit “Calculate“ again. You do not need to reload the data. elect the new tab (if necessary), reset the options and hit “Calculate” again. You do not need to reload the data.

USFUL HINT: If you wish to consider a range of methods for a series, do all the calculations first and then examine the output for each method. That way, you only need to load the data once.

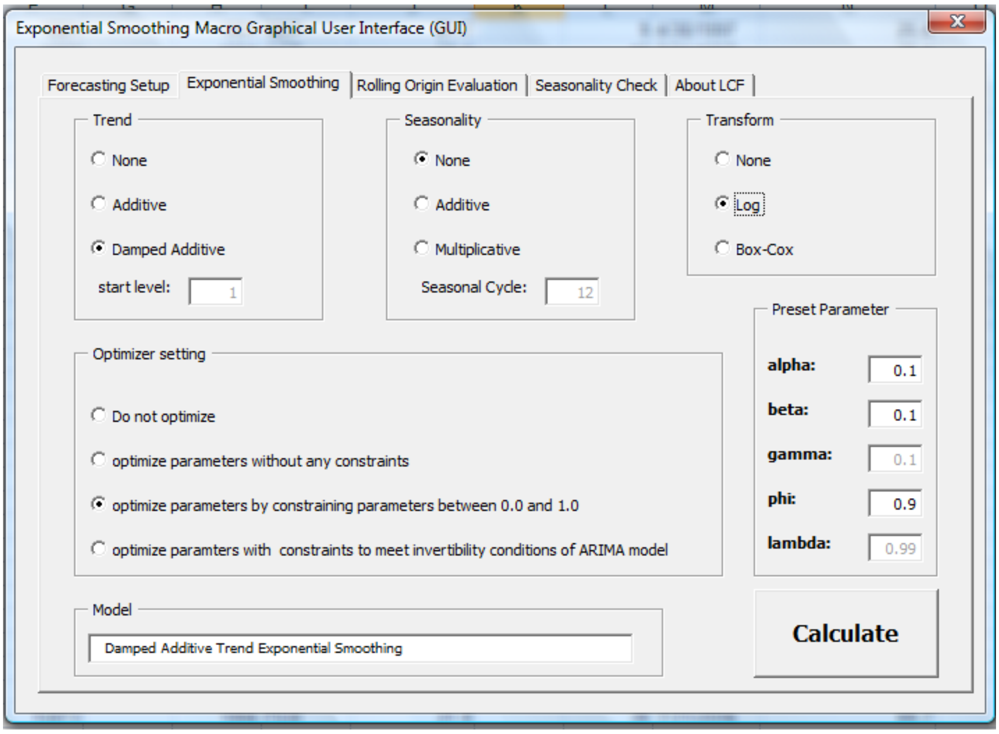
## 5. Using the damped trend exponential smoothing method with a logarithmic transformation: A demonstration

The damped trend exponential smoothing (DATES) method with a log transformation will be demonstrated for “Qsales” data. In the “Load data” tab, the “Qsales” data range was selected. Then the number of holdout sample was set at 15 and the forecasting horizon was set at 5 (Screenshot 8). The check mark for “Show error correction equations” was removed so the macro will generate the forecasts using the non-error correction equations for the DATES method.



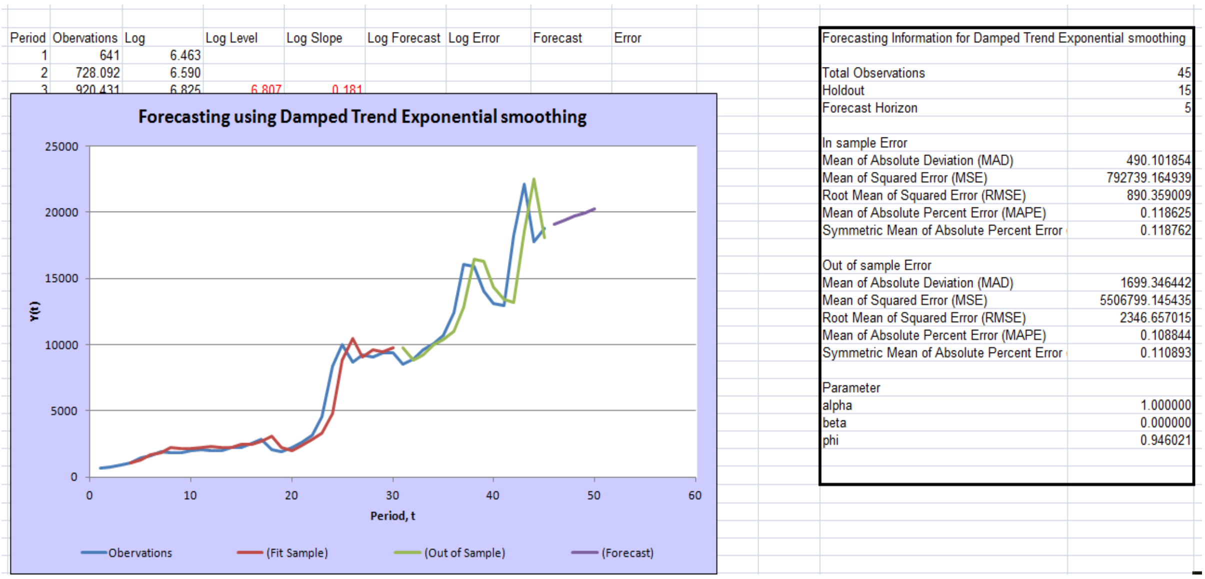

**Screenshot 8**

The model setting for the DATES method is implemented in the “Exponential Smoothing” tab. In the “Trend” box, “Damped Additive” is selected. The model name “Damped additive exponential smoothing” will be shown in the bottom text box on the screen. Because the parameters for the DATES method are unknown, search for the parameters automatically by selecting the option “optimize parameters by constraining parameters between 0.0 and 1.0”. The “Log” transformation was selected under the “Transform” option. To generate the forecasts, click on the “Calculate” button (Screenshot 9).




**Screenshot 9**

The results are generated in a separate worksheet (Screenshot 10). This worksheet contains the forecasts, plots of the (fitted and) forecast and actual series and forecast error measures. The error measures always relate to the *original* series, whether or not transformations have been applied. Users should examine the forecast errors to check the validity of the selected forecasting method. As noted, earlier, users can check how the forecasting values were calculated by selecting cells in the results worksheet.



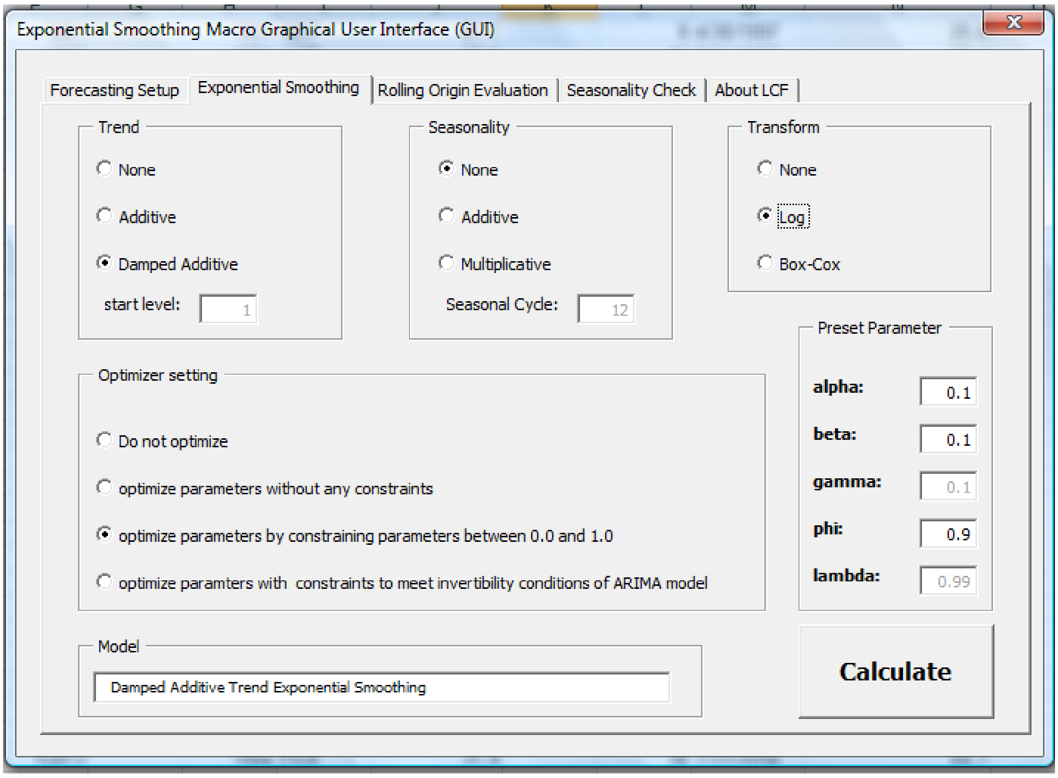

**Screenshot 10**

For this example, the series has 45 observations, 15 of which are used as the hold-out sample. The 15 one-step-ahead forecasts (in the original units) may be found on the output sheet in cells i36 –

i50. The forecast horizon was set at 5, so the one to five step-ahead forecasts are recorded in cells i51-i55. The (90 percent) prediction intervals are listed in cells q51-r55. Clearly these locations depend on the series length, the method selected, the size of the hold-out sample and the forecast horizon.

## 6. Rolling Origin Evaluation

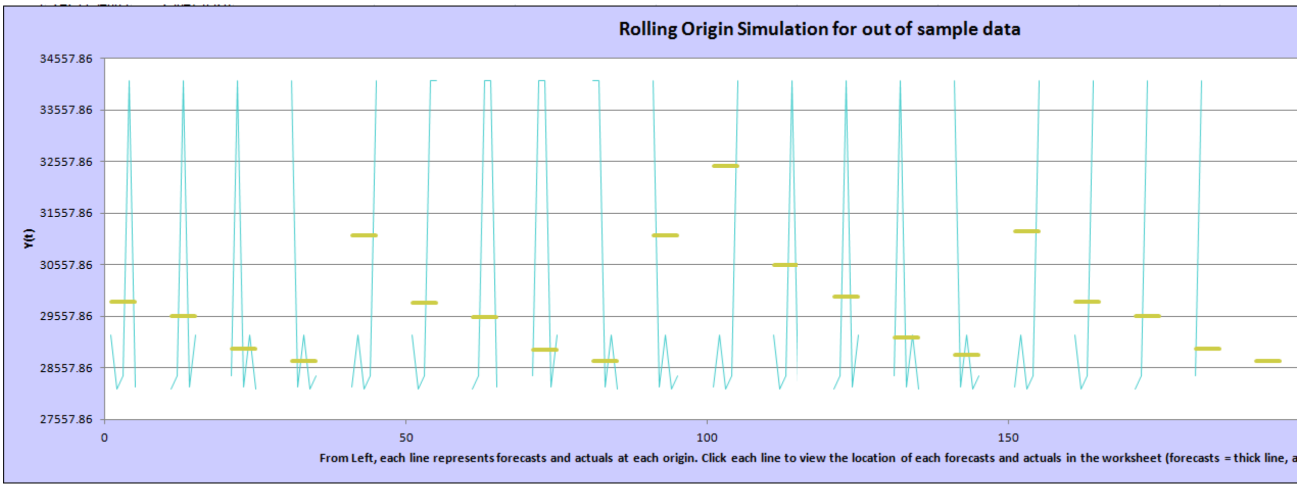
The “Rolling origin evaluation” tab provides illustrations of the rolling origin approach to evaluating forecasting methods for the single exponential smoothing (SES) and the additive trend exponential smoothing (ATES) methods; see Screenshot 11. The required steps are similar to the process described earlier and so are presented in summary form:




**Screenshot 11**

1. Load time series data in the “Forecasting Setup” tab.
2. Specify the size of the hold-out sample (The hold-out size must be greater than zero).
3. Specify the forecasting horizon.
4. Choose the method of interest (SES or ATES) to see the rolling origin evaluation.
5. Choose the initial value by setting the start level if SES is chosen; choose initial parameters and the appropriate optimizer setting.
6. Hit the “Calculate” button.

This process generates the forecasts for single exponential smoothing or additive trend exponential smoothing in a separate worksheet. The chart in the worksheet shows the actual and forecast values at each forecast origin (Screenshot 12). The forecasts at each origin are based upon the latest available data. The user can trace the location of the forecast and actual values in the spreadsheet by clicking each plot in the chart. Also, separate error measures are generated to aid the user in understanding rolling origin evaluations (Screenshot 13). Users can trace how the rolling origin error was calculated by selecting cells in the worksheet.




**Screenshot 12**

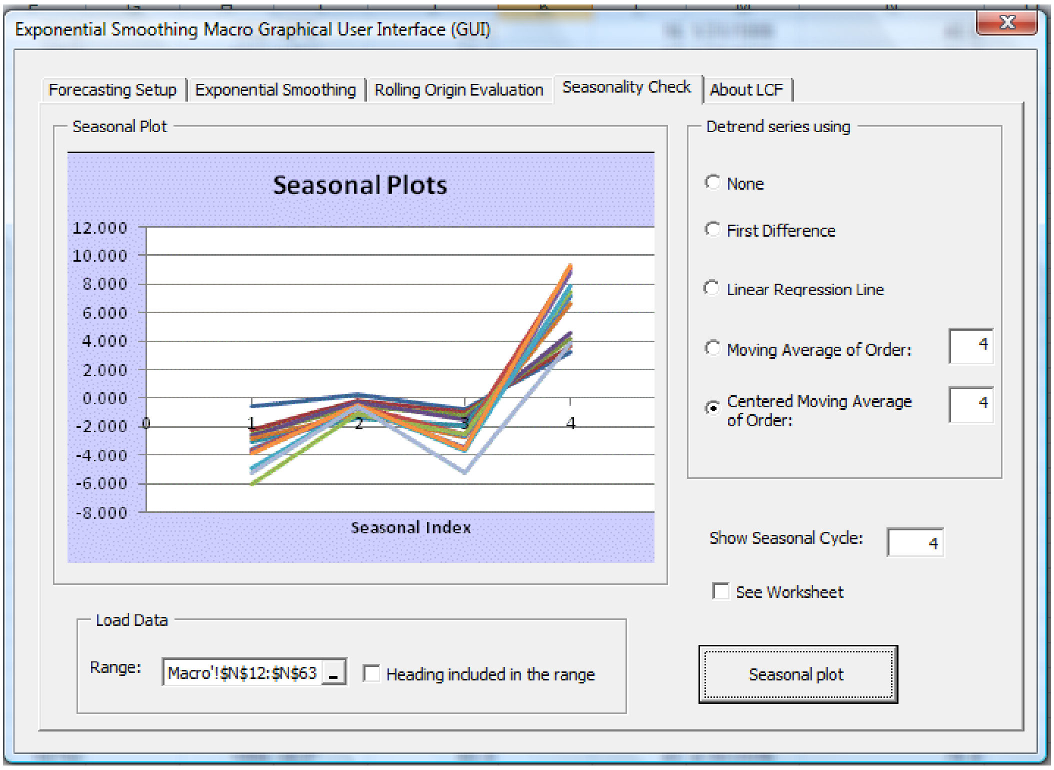
| | | | | | |
|---|---|---|---|---|---|
| Forecasting Information for Rolling Origin Evaluation using Single Exponential smoothing | | | | | |
| | | | | | |
| Total Observations | 62 | | | | |
| Holdout | 20 | | | | |
| Forecast Horizon | 5 | | | | |
| | | | | | |
| In sample Error | | | | | |
| Mean of Absolute Deviation (MAD) | 1946.850 | | | | |
| Mean of Squared Error (MSE) | 7303300.136 | | | | |
| Root Mean of Squared Error (RMSE) | 2702.462 | | | | |
| Mean of Absolute Percent Error (MAPE) | 0.060 | | | | |
| Symmetric Mean of Absolute Percent Error | 0.061 | | | | |
| | | | | | |
| Out of sample Error | | | | | |
| Mean of Absolute Deviation (MAD) | 3297.251 | | | | |
| Mean of Squared Error (MSE) | 24133131.474 | | | | |
| Root Mean of Squared Error (RMSE) | 4912.548 | | | | |
| Mean of Absolute Percent Error (MAPE) | 0.092 | | | | |
| Symmetric Mean of Absolute Percent Error | 0.090 | | | | |
| | | | | | |
| Parameter | | | | | |
| alpha | 0.701 | | | | |
| | | | | | |
| | MAD | MSE | RMSE | MAPE | SMAPE |
| Rolling Origin Evaluation | 5462.664 | 49455401.336 | 6100.615 | 0.158 | 0.151 |

**Screenshot 13**

# 7. Seasonality Check

Knowledge about the seasonal cycle is a vital element in model specification. The presence of seasonality and the length of the seasonal cycle can be checked visually using the “Seasonality Check” tab in the ESM. The required steps are:

1. Load the time series data in the “Load Data” section under the “Seasonality Check” tab.
2. Choose an appropriate detrending method to remove any trend present in the series.
3. Specify the seasonal length of interest in the “Show Seasonal Cycle” box; also, set the corresponding order for the moving average and centred moving average methods if they are chosen. (Screenshot 14 assumes that the user is interested in finding out about the presence of a seasonal cycle of length 4, using the centred moving average method.)
4. Check the “See Worksheet” box if the user wishes to find out how the seasonal plots and detrending methods work.
5. Hit the “Seasonal plot” button to generate the seasonal plot.




**Screenshot 14**

## 8. The Lancaster Centre for Forecasting (LCF)

The Lancaster Centre for Forecasting is led by past president of the International Institute of Forecasting (IIF) Professor Robert Fildes. The Centre is actively engaged in both leading forecasting associations, the IIF and the IBF (International Business Forecasting and Planning).

The LCF has expertise in three core areas in the field of predictive analytics:

Applied Forecasting

- Business consulting and applied research projects
- Demand planning in supply chains and retail
- Teaching and developing training courses in statistical methods

Data Mining

- Churn and credit scoring
- Customer Relationship Management
- Classification problems

Market Modelling

- Information and Communication Technology (ICT) research
- Diffusion modelling
- Customer behaviour analysis

The LCF offers research and consultancy services to industry, commerce and government. Its services include corporate research, courses for practitioner and consultancy services. A limited list of domestic and international clients includes:

- AstraZeneca
- Barclaycard
- British Airways
- BT (British Telecommunication Plc.)
- Co-Operative Bank
- Department of Health
- Halifax PLC
- NHS Blackpool
- Wilkinson

# 9. Appendix on parameter constraints

The conventional constraints imposed on the smoothing parameters in exponential smoothing require that that all these coefficients lie in the range [0, 1]. Some programs constrain the parameter values to lie strictly inside these ranges, but the ESM allows the boundary values. For example, single exponential smoothing with $\alpha = 0$ uses the mean of the first *K* observations as the forecast for all later periods (default *K* = 1).

A more general set of constraints is provided by the invertibility conditions of ARIMA models, which are implied by the *stability* conditions for state space models; see Hyndman, Koehler, Ord and Snyder (2008, Chapters 10 and 11) for a comprehensive but advanced discussion of this topic. For the purposes of running the ESM, the following constraints can be applied in this context if the user selects the option "optimize parameters with constraints to meet invertibility conditions of ARIMA model" in the optimizer setting. <u>Note that these constraints produce a larger parameter space than that usually specified in exponential smoothing</u>.

*Single exponential smoothing:*

$$0 < \alpha < 2$$

*Linear exponential smoothing (without damping):*

$$0 < \alpha < 2$$

$$\beta > 0$$

$$2\alpha + \beta < 4$$

In addition, if the damped version is used, we add the condition:

$$0 < \varphi < 1$$

*Holt-Winters methods:*

We impose the same conditions as for ATES along with $0 < \gamma < 1$. These conditions are not the exact set of stability conditions but are usually adequate.

Finally, the ESM constrains the power in the Box-Cox transformation to lie in the range 0 to 1. This is not necessary but serves to avoid certain numerical problems.

### Reference

Hyndman, R. J., Koehler, A. B., Ord, J. K., and Snyder, R. D. (2008). *Forecasting with Exponential Smoothing.* New York: Springer.