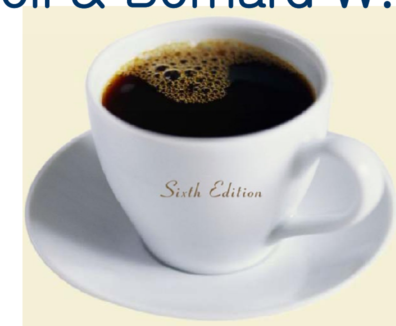
Chapter 12

Forecasting

Operations Management - 6th Edition

Roberta Russell & Bernard W. Taylor, III



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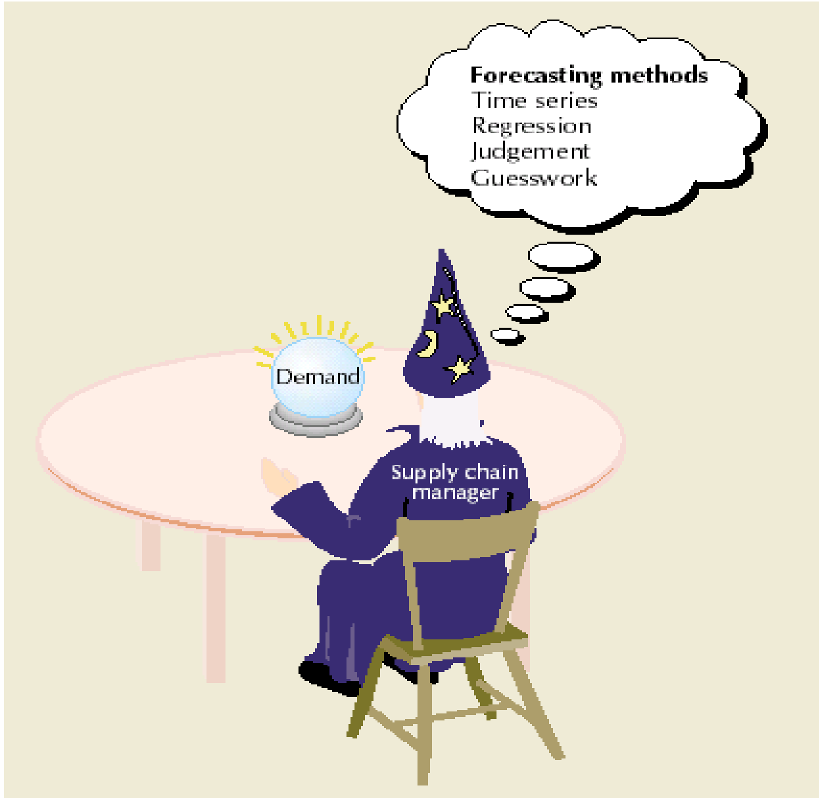
Lecture Outline

- Strategic Role of Forecasting in Supply Chain Management
- Components of Forecasting Demand
- Time Series Methods
- Forecast Accuracy
- Time Series Forecasting Using Excel
- Regression Methods

Forecasting

- Predicting the future
- Qualitative forecast methods
  - subjective
- Quantitative forecast methods
  - based on mathematical formulas



Forecasting and Supply Chain Management

- Accurate forecasting determines how much inventory a company must keep at various points along its supply chain
- Continuous replenishment
  - supplier and customer share continuously updated data
  - typically managed by the supplier
  - reduces inventory for the company
  - speeds customer delivery
- Variations of continuous replenishment
  - quick response
  - JIT (just-in-time)
  - VMI (vendor-managed inventory)
  - stockless inventory

Forecasting

- Quality Management
  - Accurately forecasting customer demand is a key to providing good quality service
- Strategic Planning
  - Successful strategic planning requires accurate forecasts of future products and markets

Types of Forecasting Methods

- Depend on
  - time frame
  - demand behavior
  - causes of behavior

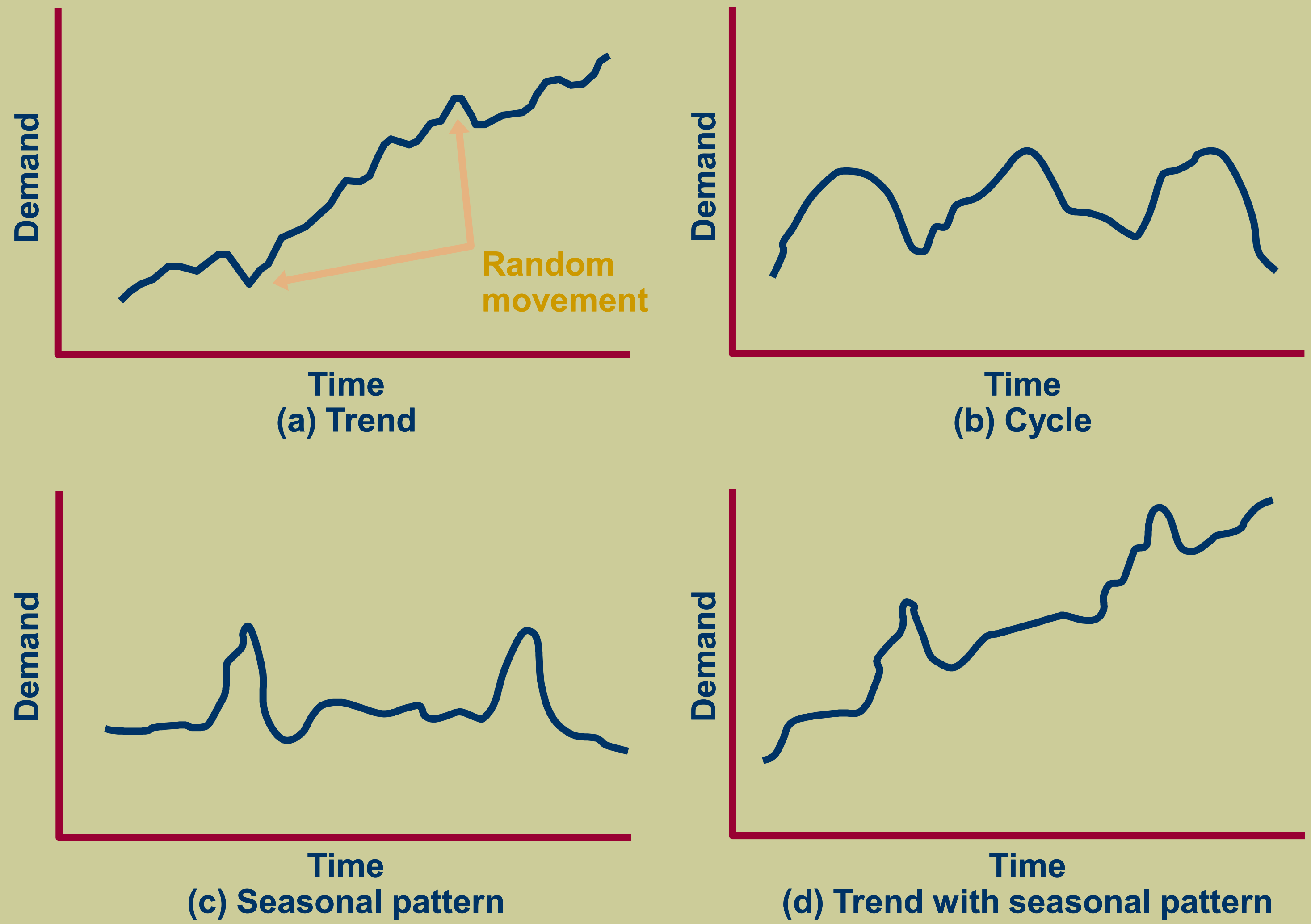
Time Frame

- Indicates how far into the future is forecast
  - Short- to mid-range forecast
    - typically encompasses the immediate future
    - daily up to two years
  - Long-range forecast
    - usually encompasses a period of time longer than two years

Demand Behavior

- Trend
  - a gradual, long-term up or down movement of demand
- Random variations
  - movements in demand that do not follow a pattern
- Cycle
  - an up-and-down repetitive movement in demand
- Seasonal pattern
  - an up-and-down repetitive movement in demand occurring periodically

Forms of Forecast Movement



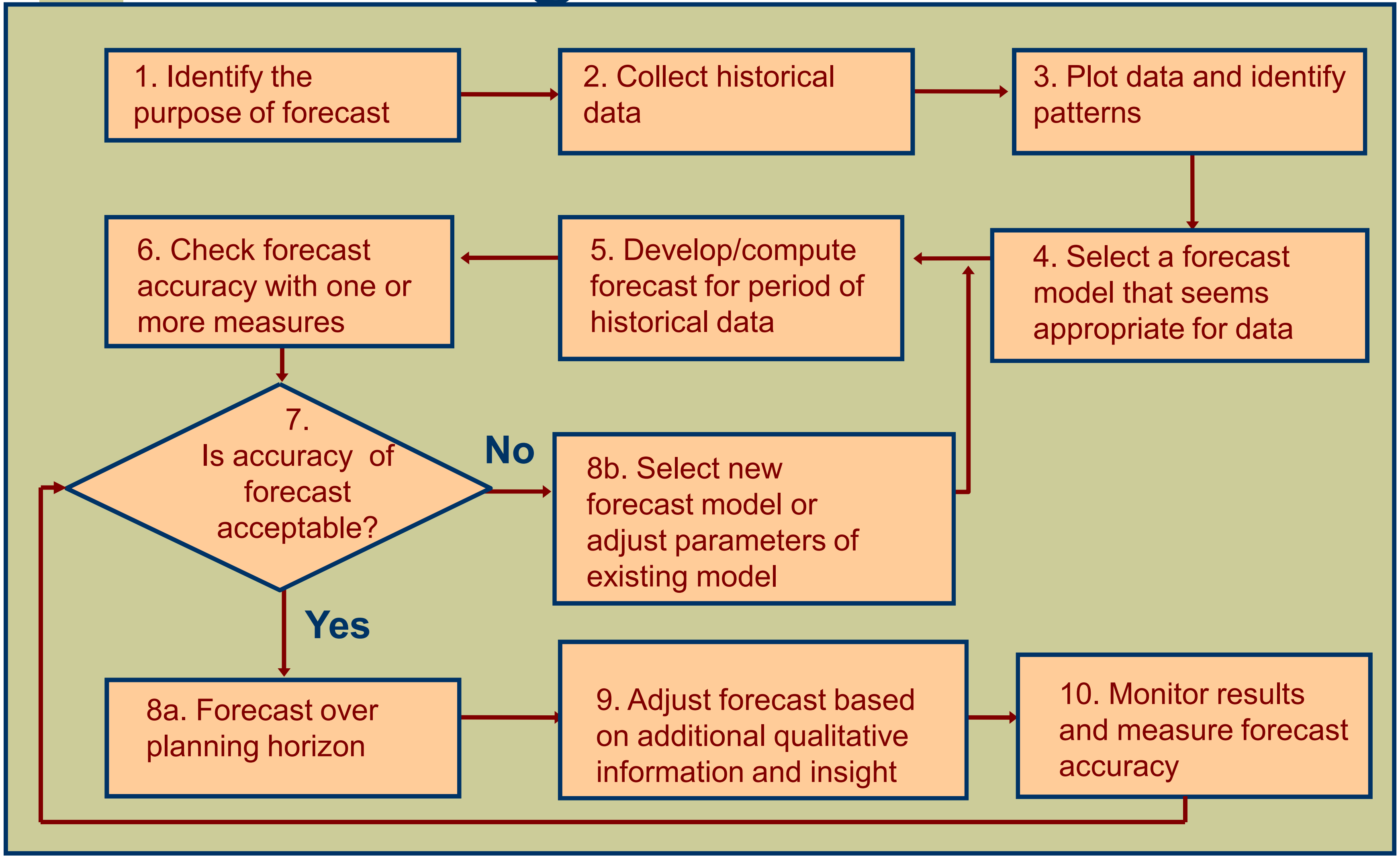
Forecasting Methods

- Time series
  - statistical techniques that use historical demand data to predict future demand
- Regression methods
  - attempt to develop a mathematical relationship between demand and factors that cause its behavior
- Qualitative
  - use management judgment, expertise, and opinion to predict future demand

Qualitative Methods

- Management, marketing, purchasing, and engineering are sources for internal qualitative forecasts
- Delphi method
  - involves soliciting forecasts about technological advances from experts

Forecasting Process



Time Series

- Assume that what has occurred in the past will continue to occur in the future
- Relate the forecast to only one factor – time
- Include
  - moving average
  - exponential smoothing
  - linear trend line

Moving Average

- *Naive* forecast
  - demand in current period is used as next period's forecast
- Simple moving average
  - uses average demand for a fixed sequence of periods
  - stable demand with no pronounced behavioral patterns
- Weighted moving average
  - weights are assigned to most recent data

Moving Average: Naïve Approach

MONTH	ORDERS PER MONTH	FORECAST
Jan	120	-
Feb	90	120
Mar	100	90
Apr	75	100
May	110	75
June	50	110
July	75	50
Aug	130	75
Sept	110	130
Oct	90	110
Nov	-	90

Simple Moving Average

$$MA_n = \frac{\sum_{i=1}^{n} D_i}{n}$$

where

n = number of periods in the moving average

D_i = demand in period i

3-month Simple Moving Average

MONTH	ORDERS PER MONTH	MOVING AVERAGE
Jan	120	–
Feb	90	–
Mar	100	–
Apr	75	103.3
May	110	88.3
June	50	95.0
July	75	78.3
Aug	130	78.3
Sept	110	85.0
Oct	90	105.0
Nov	-	110.0

$$MA_3 = \frac{\sum_{i=1}^{3} D_i}{3}$$

$$= \frac{90 + 110 + 130}{3}$$

= 110 orders
for Nov

5-month Simple Moving Average

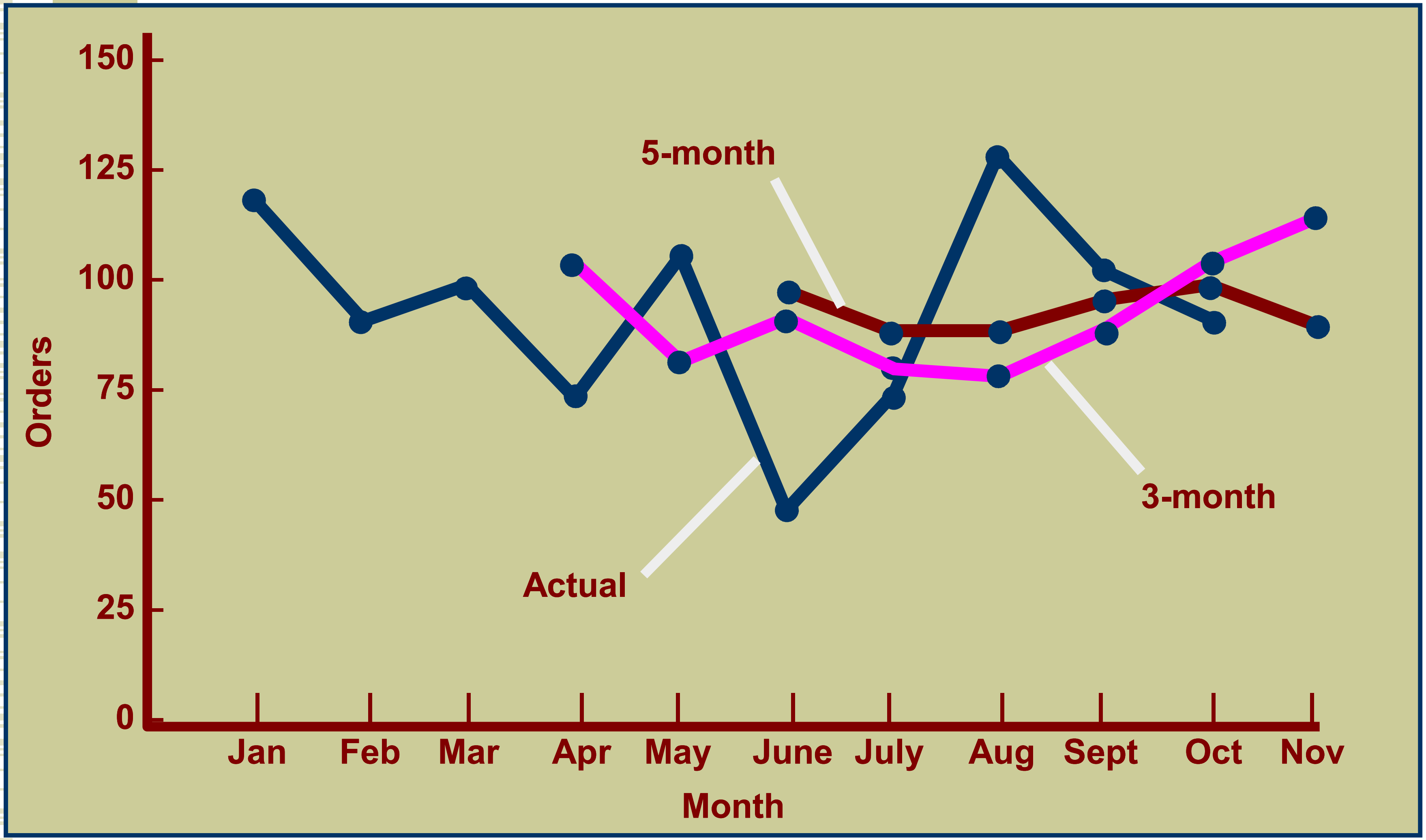
MONTH	ORDERS PER MONTH	MOVING AVERAGE
Jan	120	–
Feb	90	–
Mar	100	–
Apr	75	–
May	110	–
June	50	99.0
July	75	85.0
Aug	130	82.0
Sept	110	88.0
Oct	90	95.0
Nov	-	91.0

$$MA_5 = \frac{\sum_{i=1}^{5} D_i}{5}$$

$$= \frac{90 + 110 + 130+75+50}{5}$$

= 91 orders for Nov

Smoothing Effects



Weighted Moving Average

- Adjusts moving average method to more closely reflect data fluctuations

$$WMA_n = \sum_{i=1}^{n} W_i \, D_i$$

where

W_i = the weight for period i, between 0 and 100 percent

$$\sum W_i = 1.00$$

Weighted Moving Average Example

MONTH	WEIGHT	DATA
August	17%	130
September	33%	110
October	50%	90

November Forecast $$WMA_3 = \sum_{i=1}^{3} W_i D_i$$

$$= (0.50)(90) + (0.33)(110) + (0.17)(130)$$

$$= 103.4 \text{ orders}$$

Exponential Smoothing

- Averaging method
- Weights most recent data more strongly
- Reacts more to recent changes
- Widely used, accurate method

Exponential Smoothing (cont.)

$$F_{t+1} = \alpha D_t + (1 - \alpha)F_t$$

where:

F_{t+1} = forecast for next period

D_t = actual demand for present period

F_t = previously determined forecast for present period

α = weighting factor, smoothing constant

Effect of Smoothing Constant

$$0.0 \leq \alpha \leq 1.0$$

If $\alpha = 0.20$, then $F_{t+1} = 0.20\,D_t + 0.80\,F_t$

If $\alpha = 0$, then $F_{t+1} = 0\,D_t + 1\,F_t = F_t$

Forecast does not reflect recent data

If $\alpha = 1$, then $F_{t+1} = 1\,D_t + 0\,F_t = D_t$

Forecast based only on most recent data

Exponential Smoothing (α=0.30)

PERIOD	MONTH	DEMAND
1	Jan	37
2	Feb	40
3	Mar	41
4	Apr	37
5	May	45
6	Jun	50
7	Jul	43
8	Aug	47
9	Sep	56
10	Oct	52
11	Nov	55
12	Dec	54

$$F_2 = \alpha D_1 + (1 - \alpha)F_1$$
$$= (0.30)(37) + (0.70)(37)$$
$$= 37$$

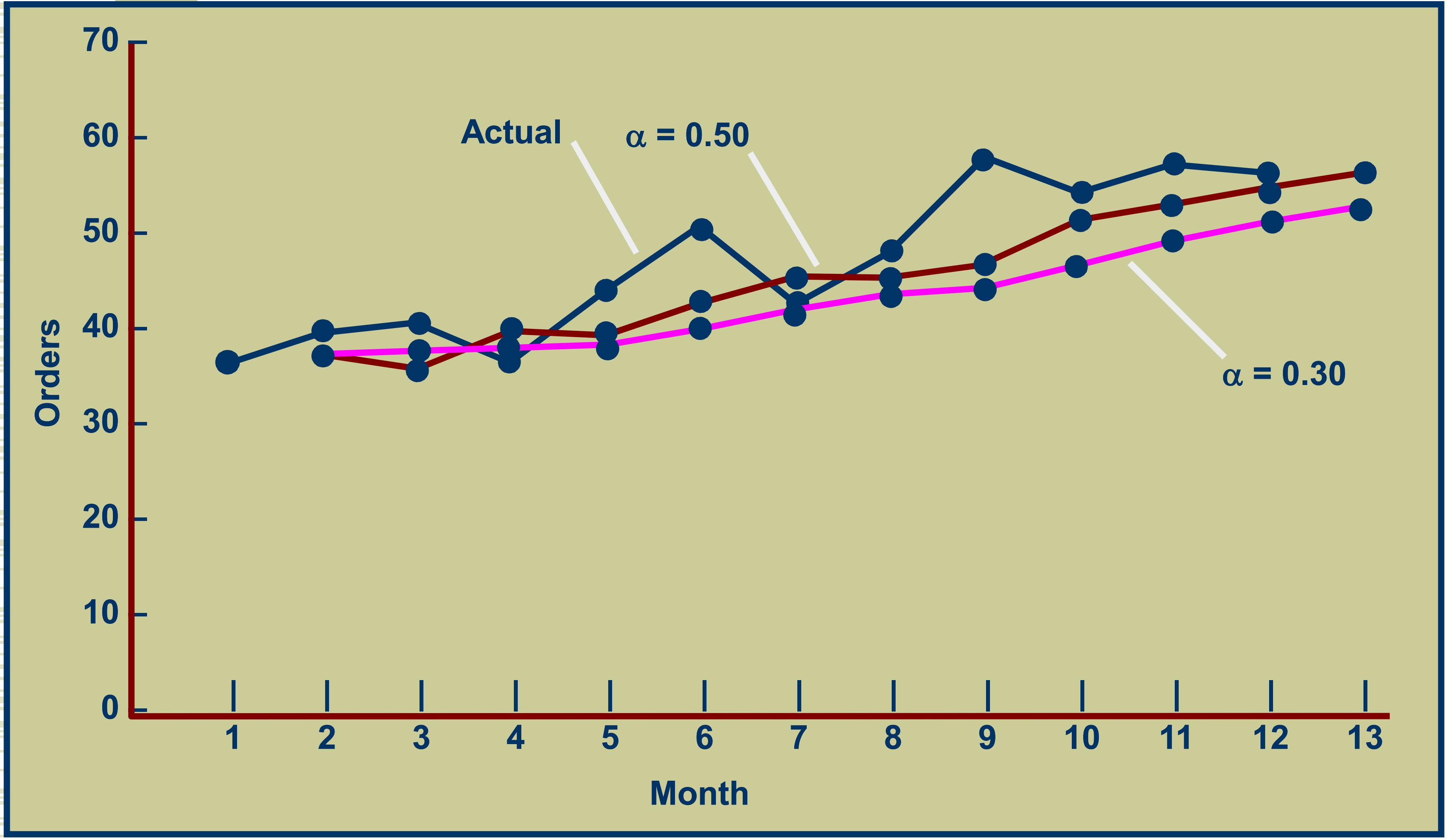
$$F_3 = \alpha D_2 + (1 - \alpha)F_2$$
$$= (0.30)(40) + (0.70)(37)$$
$$= 37.9$$

$$F_{13} = \alpha D_{12} + (1 - \alpha)F_{12}$$
$$= (0.30)(54) + (0.70)(50.84)$$
$$= 51.79$$

Exponential Smoothing (cont.)

PERIOD	MONTH	DEMAND	FORECAST, F_{t+1} ($\alpha = 0.3$)	($\alpha = 0.5$)
1	Jan	37	–	–
2	Feb	40	37.00	37.00
3	Mar	41	37.90	38.50
4	Apr	37	38.83	39.75
5	May	45	38.28	38.37
6	Jun	50	40.29	41.68
7	Jul	43	43.20	45.84
8	Aug	47	43.14	44.42
9	Sep	56	44.30	45.71
10	Oct	52	47.81	50.85
11	Nov	55	49.06	51.42
12	Dec	54	50.84	53.21
13	Jan	–	51.79	53.61

Exponential Smoothing (cont.)



Adjusted Exponential Smoothing

$$AF_{t+1} = F_{t+1} + T_{t+1}$$

where

T = an exponentially smoothed trend factor

$$T_{t+1} = \beta(F_{t+1} - F_t) + (1 - \beta)\, T_t$$

where

T_t = the last period trend factor

β = a smoothing constant for trend

Adjusted Exponential Smoothing (β=0.30)

PERIOD	MONTH	DEMAND
1	Jan	37
2	Feb	40
3	Mar	41
4	Apr	37
5	May	45
6	Jun	50
7	Jul	43
8	Aug	47
9	Sep	56
10	Oct	52
11	Nov	55
12	Dec	54

$T_3 = \beta(F_3 - F_2) + (1 - \beta)\, T_2$

$= (0.30)(38.5 - 37.0) + (0.70)(0)$

$= 0.45$

$AF_3 = F_3 + T_3 = 38.5 + 0.45$

$= 38.95$

$T_{13} = \beta(F_{13} - F_{12}) + (1 - \beta)\, T_{12}$

$= (0.30)(53.61 - 53.21) + (0.70)(1.77)$

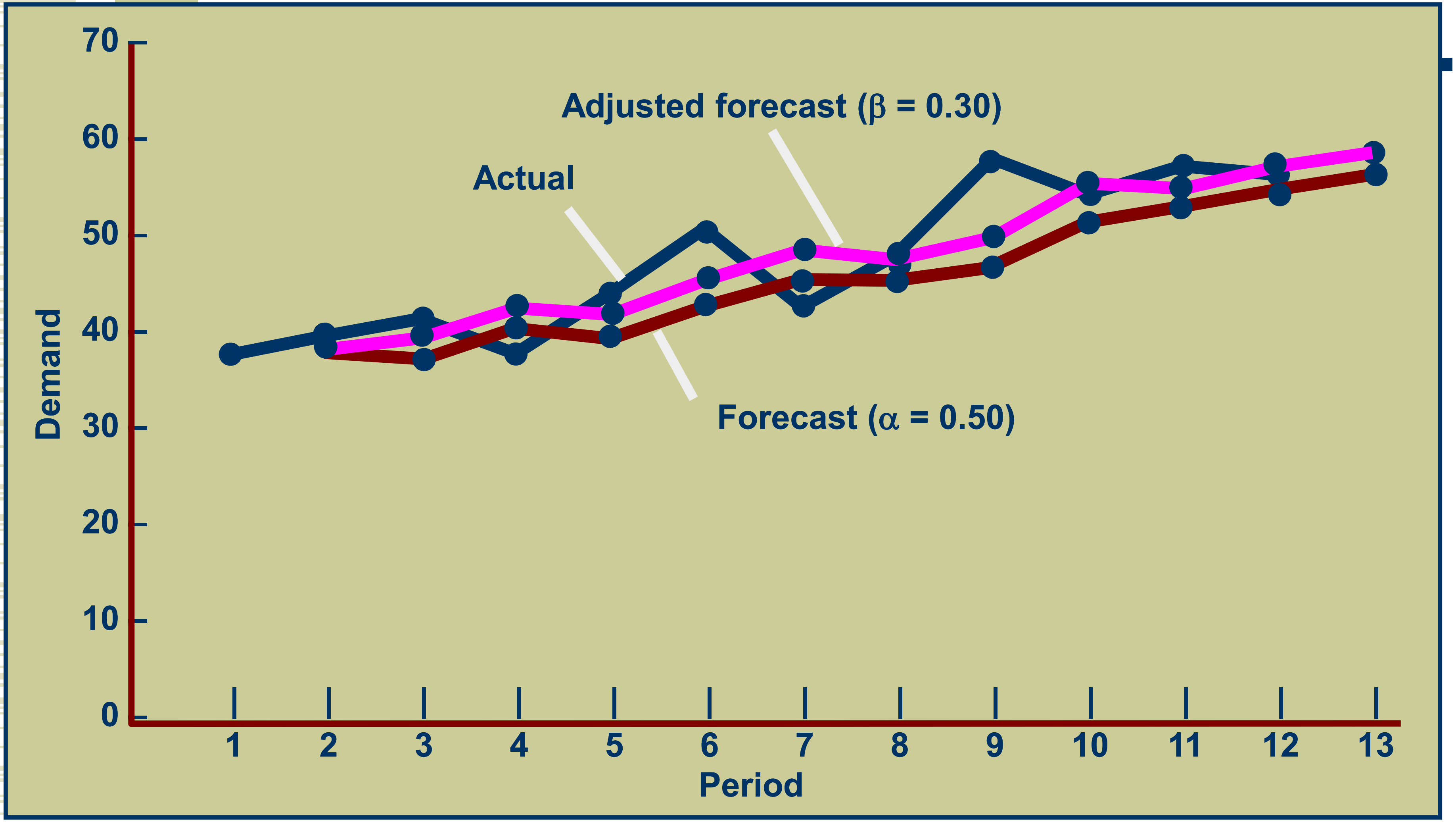
$= 1.36$

$AF_{13} = F_{13} + T_{13} = 53.61 + 1.36 = 54.97$

Adjusted Exponential Smoothing: Example

PERIOD	MONTH	DEMAND	FORECAST F_{t+1}	TREND T_{t+1}	ADJUSTED FORECAST AF_{t+1}
1	Jan	37	37.00	–	–
2	Feb	40	37.00	0.00	37.00
3	Mar	41	38.50	0.45	38.95
4	Apr	37	39.75	0.69	40.44
5	May	45	38.37	0.07	38.44
6	Jun	50	38.37	0.07	38.44
7	Jul	43	45.84	1.97	47.82
8	Aug	47	44.42	0.95	45.37
9	Sep	56	45.71	1.05	46.76
10	Oct	52	50.85	2.28	58.13
11	Nov	55	51.42	1.76	53.19
12	Dec	54	53.21	1.77	54.98
13	Jan	–	53.61	1.36	54.96

Adjusted Exponential Smoothing Forecasts



Linear Trend Line

$y = a + bx$

where
a = intercept
b = slope of the line
x = time period
y = forecast for demand for period x

$$b = \frac{\Sigma xy - n\bar{x}\bar{y}}{\Sigma x^2 - n\bar{x}^2}$$

$$a = \bar{y} - b\,\bar{x}$$

where
n = number of periods

$\bar{x} = \frac{\Sigma x}{n}$ = mean of the x values

$\bar{y} = \frac{\Sigma y}{n}$ = mean of the y values

Least Squares Example

x(PERIOD)	y(DEMAND)	xy	x^2
1	73	37	1
2	40	80	4
3	41	123	9
4	37	148	16
5	45	225	25
6	50	300	36
7	43	301	49
8	47	376	64
9	56	504	81
10	52	520	100
11	55	605	121
12	54	648	144
78	557	3867	650

Least Squares Example (cont.)

$$\bar{x} = \frac{78}{12} = 6.5$$

$$\bar{y} = \frac{557}{12} = 46.42$$

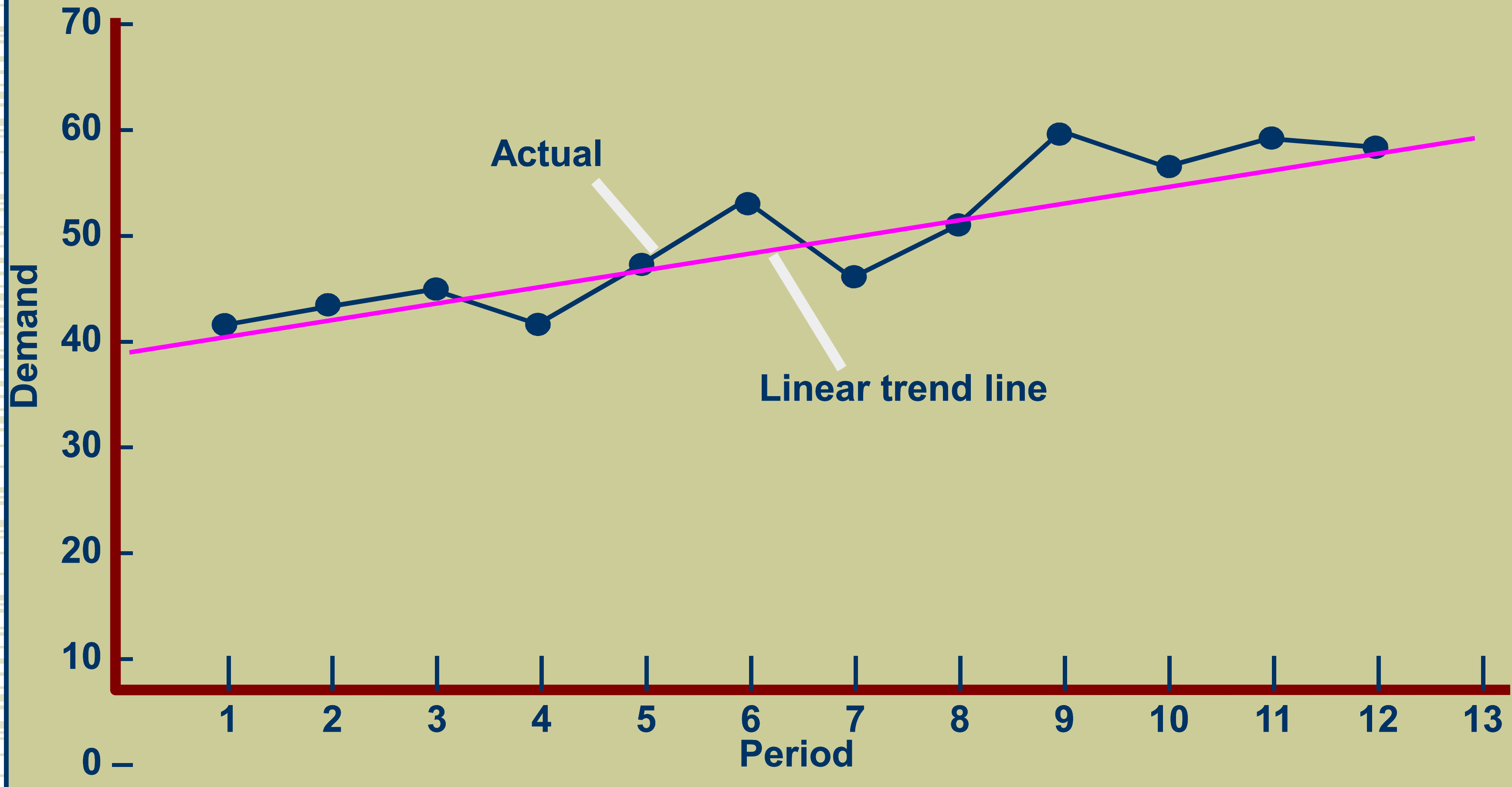
$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2} = \frac{3867 - (12)(6.5)(46.42)}{650 - 12(6.5)^2} = 1.72$$

$$a = \bar{y} - b\bar{x}$$

$$= 46.42 - (1.72)(6.5) = 35.2$$

Linear trend line $y = 35.2 + 1.72x$

Forecast for period 13 $y = 35.2 + 1.72(13) = 57.56$ units



Seasonal Adjustments

- Repetitive increase/ decrease in demand
- Use seasonal factor to adjust forecast

$$\text{Seasonal factor} = S_i = \frac{D_i}{\sum D}$$

Seasonal Adjustment (cont.)

	DEMAND (1000'S PER QUARTER)				
YEAR	*1*	*2*	*3*	*4*	*Total*
2002	12.6	8.6	6.3	17.5	45.0
2003	14.1	10.3	7.5	18.2	50.1
2004	15.3	10.6	8.1	19.6	53.6
Total	42.0	29.5	21.9	55.3	148.7

$$S_1 = \frac{D_1}{\sum D} = \frac{42.0}{148.7} = 0.28$$

$$S_3 = \frac{D_3}{\sum D} = \frac{21.9}{148.7} = 0.15$$

$$S_2 = \frac{D_2}{\sum D} = \frac{29.5}{148.7} = 0.20$$

$$S_4 = \frac{D_4}{\sum D} = \frac{55.3}{148.7} = 0.37$$

Seasonal Adjustment (cont.)

For 2005

$$y = 40.97 + 4.30x = 40.97 + 4.30(4) = 58.17$$

$$SF_1 = (S_1)(F_5) = (0.28)(58.17) = 16.28$$
$$SF_2 = (S_2)(F_5) = (0.20)(58.17) = 11.63$$
$$SF_3 = (S_3)(F_5) = (0.15)(58.17) = 8.73$$
$$SF_4 = (S_4)(F_5) = (0.37)(58.17) = 21.53$$

Forecast Accuracy

- Forecast error
  - difference between forecast and actual demand
  - MAD
    - mean absolute deviation
  - MAPD
    - mean absolute percent deviation
  - Cumulative error
  - Average error or bias

Mean Absolute Deviation (MAD)

$$\text{MAD} = \frac{\Sigma | D_t - F_t |}{n}$$

where

t = period number
D_t = demand in period t
F_t = forecast for period t
n = total number of periods
$| \ |$ = absolute value

MAD Example

PERIOD	DEMAND, D_t	F_t (α =0.3)	(D_t - F_t)	|D_t - F_t|
1	37	37.00	–	–
2				3.00
3				3.10
4				1.83
5				6.72
6				9.69
7				0.20
8				3.86
9				1.70
10				4.19
11				5.94
12	54	50.84	3.15	3.15
	557		49.31	53.39

$$\text{MAD} = \frac{\Sigma| D_t - F_t |}{n}$$

$$= \frac{53.39}{11}$$

$$= 4.85$$

Other Accuracy Measures

Mean absolute percent deviation (MAPD)

$$MAPD = \frac{\sum|D_t - F_t|}{\sum D_t}$$

Cumulative error

$$E = \sum e_t$$

Average error

$$E = \frac{\sum e_t}{n}$$

Comparison of Forecasts

FORECAST	MAD	MAPD	*E*	($\bar{E}$)
Exponential smoothing (α = 0.30)	4.85	9.6%	49.31	4.48
Exponential smoothing (α = 0.50)	4.04	8.5%	33.21	3.02
Adjusted exponential smoothing (α = 0.50, β = 0.30)	3.81	7.5%	21.14	1.92
Linear trend line	2.29	4.9%	–	–

Forecast Control

- Tracking signal
  - monitors the forecast to see if it is biased high or low

$$\text{Tracking signal} = \frac{\sum(D_t - F_t)}{\text{MAD}} = \frac{E}{\text{MAD}}$$

  - 1 MAD ≈ 0.8 б
  - Control limits of 2 to 5 MADs are used most frequently

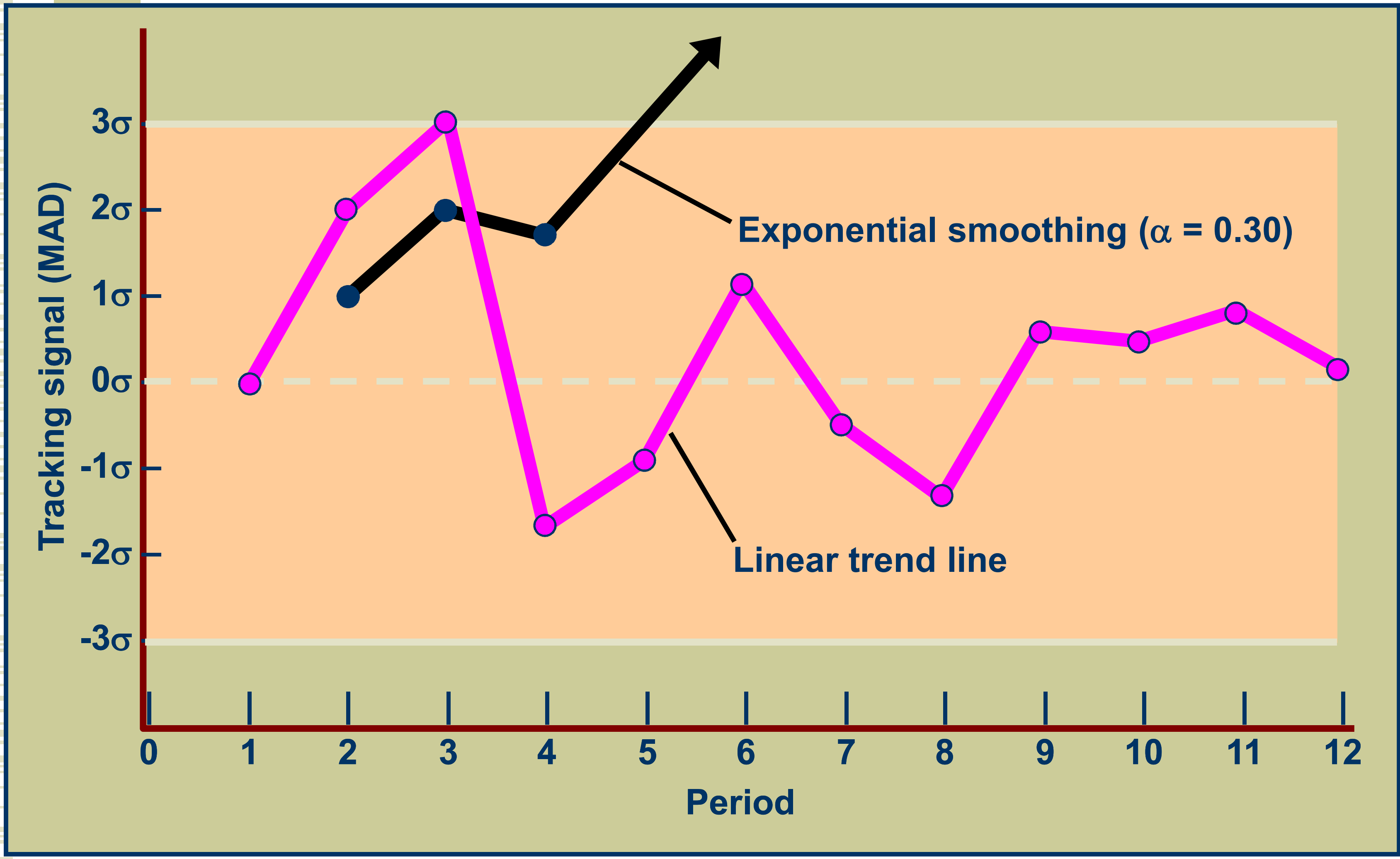
Tracking Signal Values

PERIOD	DEMAND D_t	FORECAST, F_t	ERROR $D_t - F_t$	$\sum E = \sum(D_t - F_t)$	MAD	TRACKING SIGNAL
1	37	37.00	–	–	–	–
2	40	37.00	3.00	3.00	3.00	1.00
3	41	37.90	3.10	6.10	3.05	2.00
4	37	[illegible]	[illegible]	[illegible]	[illegible]	1.62
5	45	[illegible]	[illegible]	[illegible]	[illegible]	3.00
6	50	[illegible]	[illegible]	[illegible]	[illegible]	4.25
7	43	[illegible]	[illegible]	[illegible]	[illegible]	5.01
8	47	[illegible]	[illegible]	[illegible]	[illegible]	6.00
9	56	[illegible]	[illegible]	[illegible]	[illegible]	7.19
10	52	[illegible]	[illegible]	[illegible]	[illegible]	8.18
11	55	49.06	3.94	46.17	5.02	9.20
12	54	50.84	3.15	49.32	4.85	10.17

Tracking signal for period 3

$$TS_3 = \frac{6.10}{3.05} = 2.00$$

Tracking Signal Plot

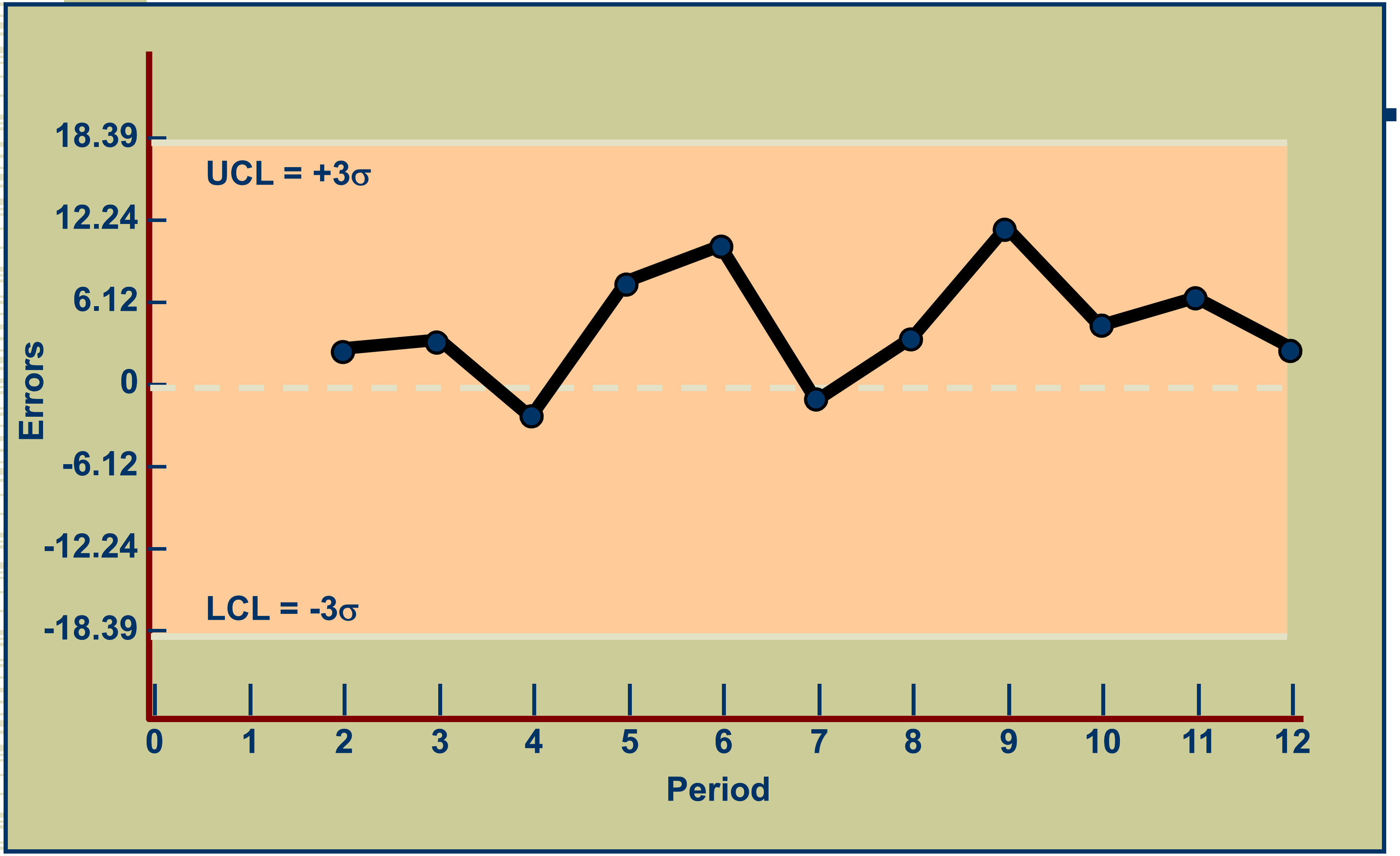


Statistical Control Charts

$$\sigma = \sqrt{\frac{\sum(D_t - F_t)^2}{n - 1}}$$

- Using σ we can calculate statistical control limits for the forecast error
- Control limits are typically set at $\pm 3\sigma$

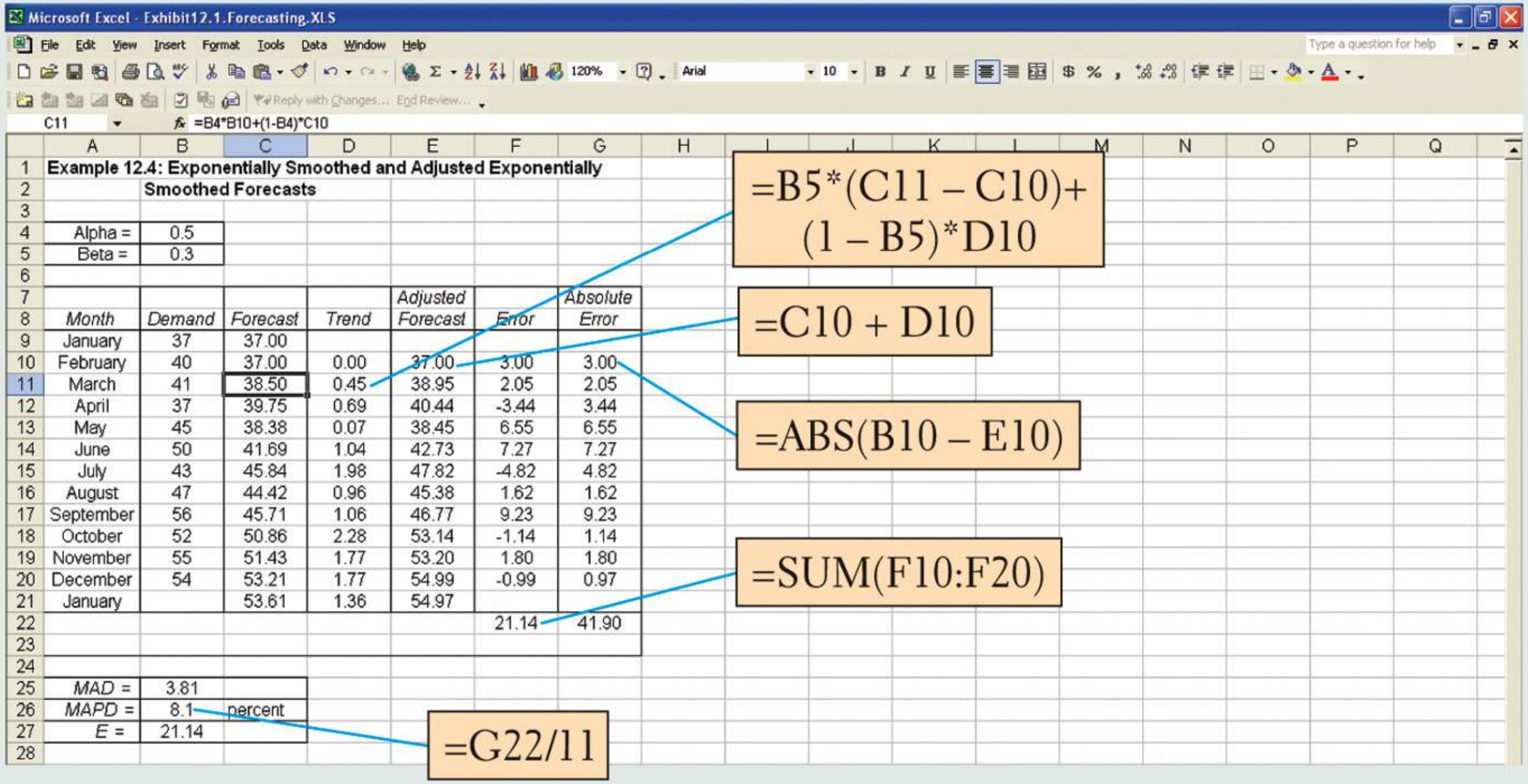
Statistical Control Charts



Time Series Forecasting using Excel

- Excel can be used to develop forecasts:
  - Moving average
  - Exponential smoothing
  - Adjusted exponential smoothing
  - Linear trend line

Exponentially Smoothed and Adjusted Exponentially Smoothed Forecasts



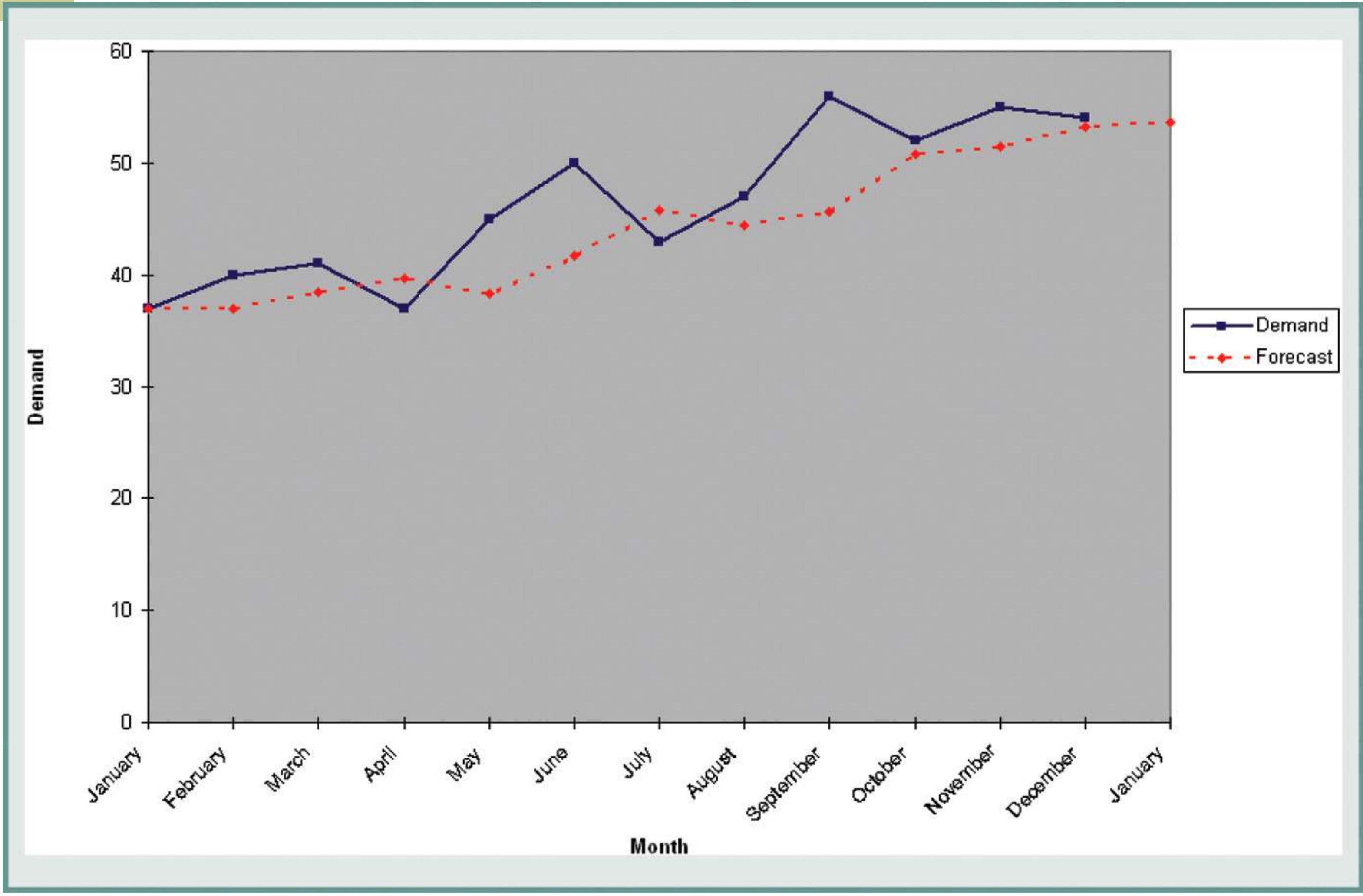
Example 12.4: Exponentially Smoothed and Adjusted Exponentially Smoothed Forecasts

Alpha =	0.5
Beta =	0.3

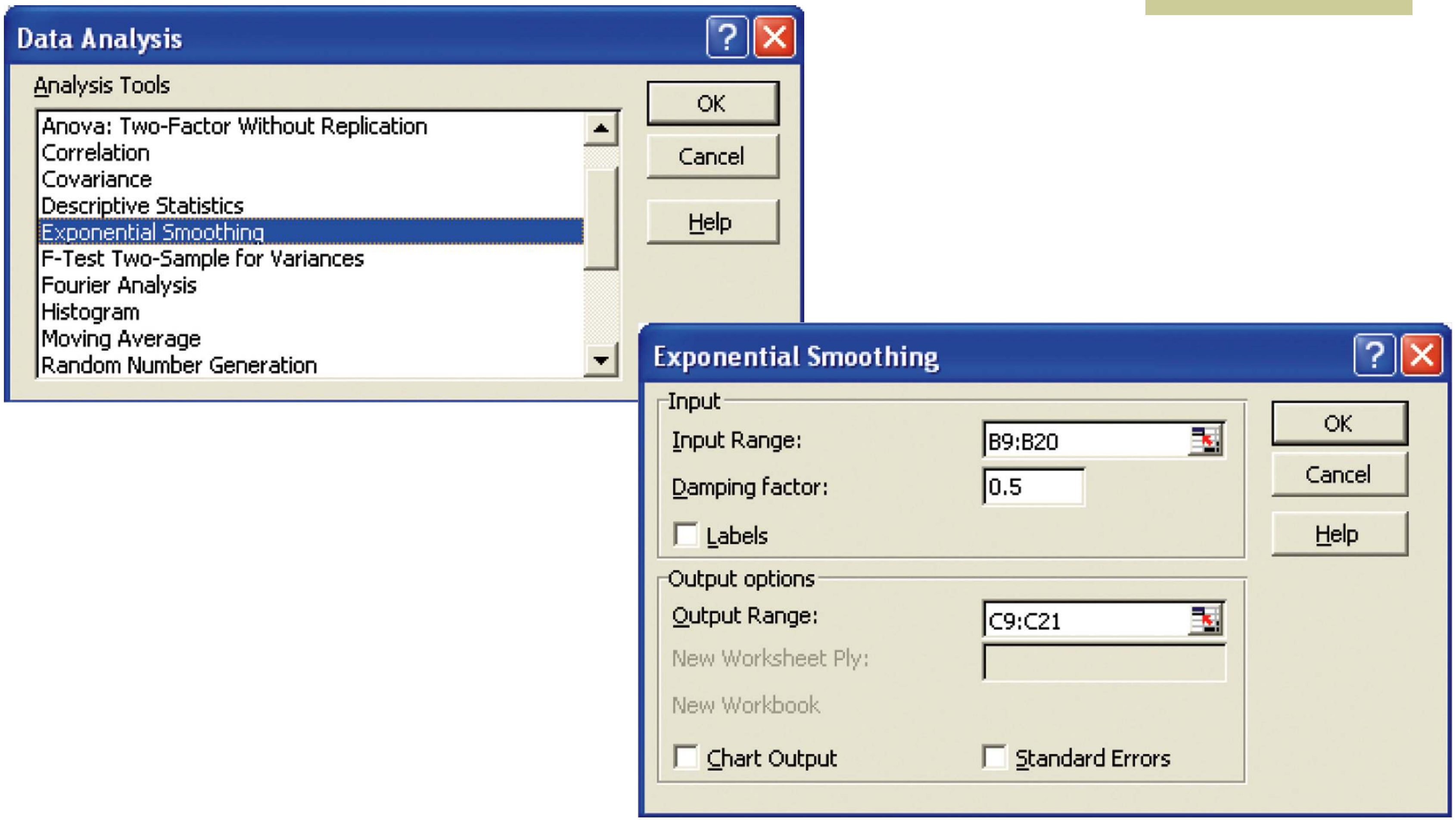
Month	Demand	Forecast	Trend	Adjusted Forecast	Error	Absolute Error
January	37	37.00				
February	40	37.00	0.00	37.00	3.00	3.00
March	41	38.50	0.45	38.95	2.05	2.05
April	37	39.75	0.69	40.44	-3.44	3.44
May	45	38.38	0.07	38.45	6.55	6.55
June	50	41.69	1.04	42.73	7.27	7.27
July	43	45.84	1.98	47.82	-4.82	4.82
August	47	44.42	0.96	45.38	1.62	1.62
September	56	45.71	1.06	46.77	9.23	9.23
October	52	50.86	2.28	53.14	-1.14	1.14
November	55	51.43	1.77	53.20	1.80	1.80
December	54	53.21	1.77	54.99	-0.99	0.97
January		53.61	1.36	54.97		
					21.14	41.90

MAD =	3.81	
MAPD =	8.1	percent
E =	21.14	

Demand and exponentially smoothed forecast



Data Analysis option



Computing a Forecast with Seasonal Adjustment

Microsoft Excel - Exhibit12.5.Forecasting.XLS

B12 =(B8/F8)*E10

	A	B	C	D	E	F	G
1	**Example 12.6: Computing a Forecast with Seasonal Adjustments**						
2							
3		***Demand (1,000s) per Quarter***					
4	***Year***	*1*	*2*	*3*	*4*	***Total***	
5	2002	12.6	8.6	6.3	17.5	45.0	
6	2003	14.1	10.3	7.5	18.2	50.1	
7	2004	15.3	10.6	8.1	19.6	53.6	
8	***Total***	42.0	29.5	21.9	55.3	148.7	
9							
10	Linear trend line forecast for 2005 =				58.17		
11							
12	*SF1* =	16.43					
13	*SF2* =	11.54					
14	*SF3* =	8.57					
15	*SF4* =	21.63					
16							

OM Tools

Microsoft Excel - Exhibit12.6.ExponentialSmoothing.xls

C24 =E21/(D3-1)

Exponentially Smoothed Forecasts OM Student - Example 12.3

Input:

No. of demand periods	12
Alpha	0.30

Label periods, input demand data and smoothing constant, alpha. Scroll down for output values.

Period	Demand	Forecast	Error	Absolute Error	Squared Error
January	37	37.00			
February	40	37.00	3.00	3.00	9.00
March	41	37.90	3.10	3.10	9.61
April	37	38.83	-1.83	1.83	3.35
May	45	38.28	6.72	6.72	45.14
June	50	40.30	9.70	9.70	94.15
July	43	43.21	-0.21	0.21	0.04
August	47	43.15	3.85	3.85	14.86
September	56	44.30	11.70	11.70	136.85
October	52	47.81	4.19	4.19	17.55
November	55	49.07	5.93	5.93	35.19
December	54	50.85	3.15	3.15	9.94
Total	557.00		49.31	53.39	375.68

Output:

MAD	4.85
MAPD	0.10
E	49.31
$\bar{E}$	4.48
MSE	37.57

$$MAD = \frac{\Sigma|D_t - F_t|}{n}$$

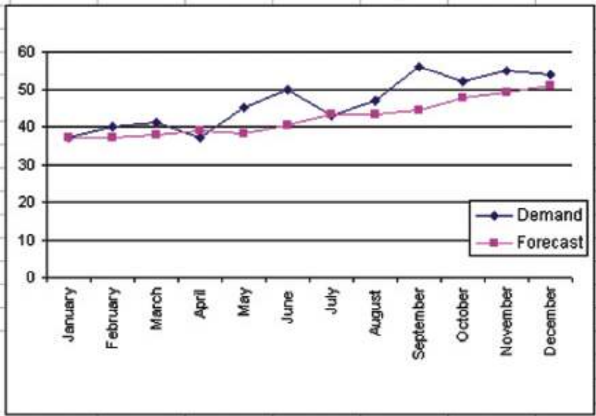
$$MAPD = \frac{\Sigma|D_t - F_t|}{D_t}$$

$$\bar{E} = \frac{\Sigma e_t}{n}$$

$$MSE = \frac{\Sigma(D_t - F_t)^2}{n-1}$$

Exponential Smoothing

$$F_{t+1} = \alpha D_t + (1 - \alpha)F_t$$



Regression Methods

- Linear regression
  - a mathematical technique that relates a dependent variable to an independent variable in the form of a linear equation
- Correlation
  - a measure of the strength of the relationship between independent and dependent variables

Linear Regression

$$y = a + bx$$

$$a = \bar{y} - b\,\bar{x}$$

$$b = \frac{\Sigma\, xy - n\bar{x}\bar{y}}{\Sigma\, x^2 - n\bar{x}^2}$$

where

a = intercept

b = slope of the line

$\bar{x} = \dfrac{\Sigma\, x}{n}$ = mean of the x data

$\bar{y} = \dfrac{\Sigma\, y}{n}$ = mean of the y data

Linear Regression Example

x (WINS)	y (ATTENDANCE)	xy	x^2
4	36.3	145.2	16
6	40.1	240.6	36
6	41.2	247.2	36
8	53.0	424.0	64
6	44.0	264.0	36
7	45.6	319.2	49
5	39.0	195.0	25
7	47.5	332.5	49
49	346.7	2167.7	311

Linear Regression Example (cont.)

$$\bar{x} = \frac{49}{8} = 6.125$$

$$\bar{y} = \frac{346.9}{8} = 43.36$$

$$b = \frac{\sum xy - n\bar{x}\bar{y}^2}{\sum x^2 - n\bar{x}^2}$$

$$= \frac{(2{,}167.7) - (8)(6.125)(43.36)}{(311) - (8)(6.125)^2}$$

$$= 4.06$$

$$a = \bar{y} - b\bar{x}$$

$$= 43.36 - (4.06)(6.125)$$

$$= 18.46$$

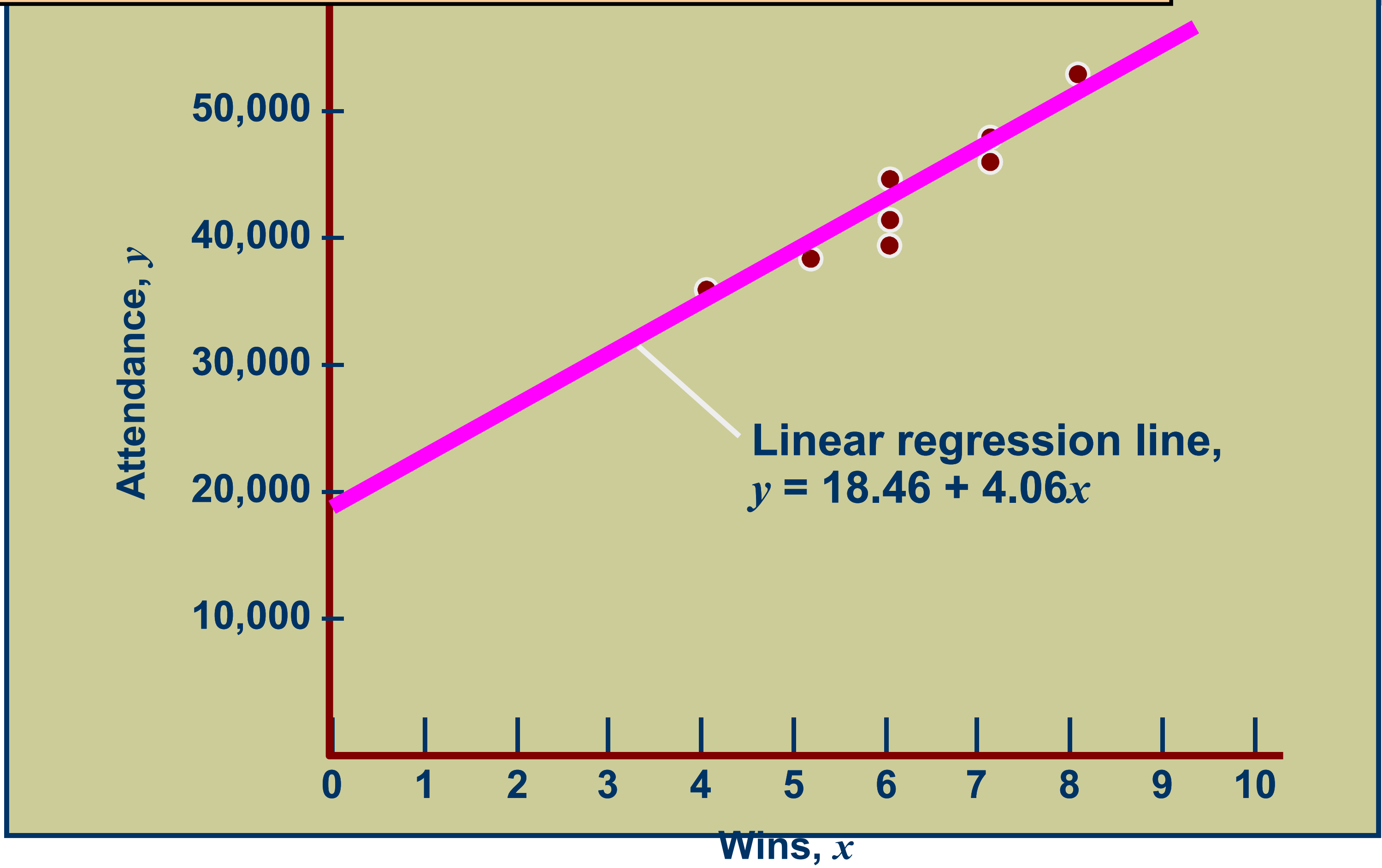
Linear Regression Example (cont.)

Regression equation

$y = 18.46 + 4.06x$

Attendance forecast for 7 wins

$y = 18.46 + 4.06(7)$
$= 46.88$, or 46,880



Correlation and Coefficient of Determination

- Correlation, r
  - Measure of strength of relationship
  - Varies between -1.00 and +1.00
- Coefficient of determination, r^2
  - Percentage of variation in dependent variable resulting from changes in the independent variable

Computing Correlation

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2]\,[n\sum y^2 - (\sum y)^2]}}$$

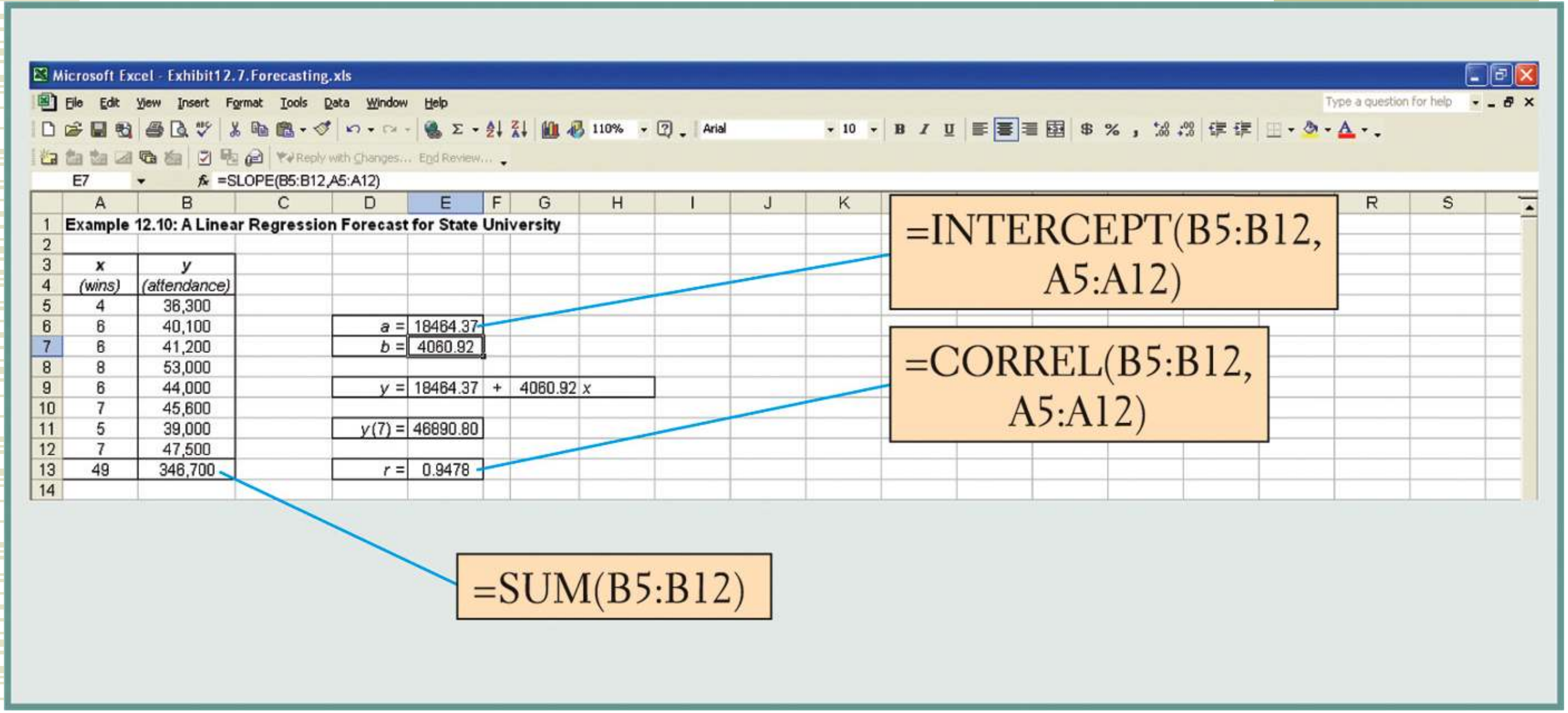
$$r = \frac{(8)(2{,}167.7) - (49)(346.9)}{\sqrt{[(8)(311) - (49)^2]\,[(8)(15{,}224.7) - (346.9)^2]}}$$

$$r = 0.947$$

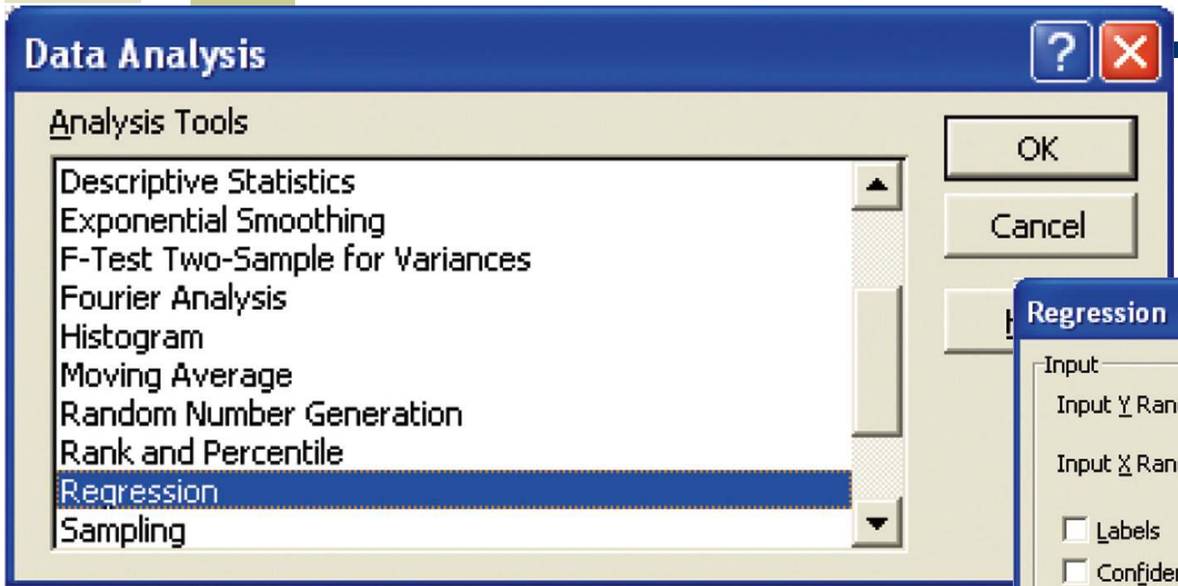
Coefficient of determination

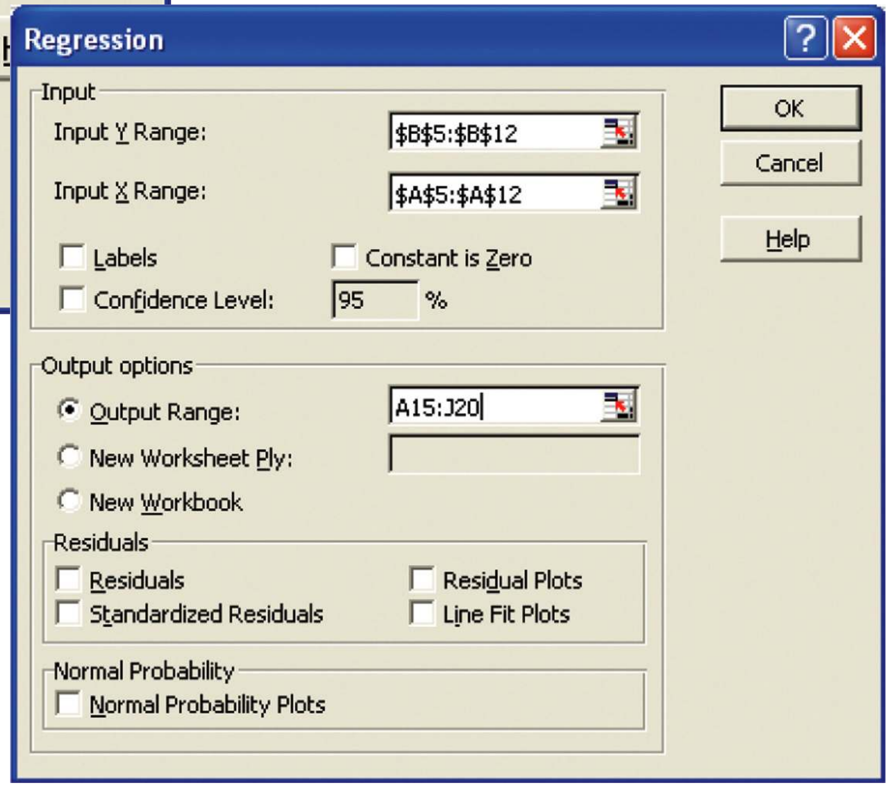
$$r^2 = (0.947)^2 = 0.897$$

Regression Analysis with Excel



Regression Analysis with Excel (cont.)





Regression Analysis with Excel (cont.)

Microsoft Excel - Exhibit12.10.Forecasting.xls

Example 12.10: State University Athletic Department

x (wins)	y (attendance)
4	36,300
6	40,100
6	41,200
8	53,000
6	44,000
7	45,600
5	39,000
7	47,500
49	346,700

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.948
R Square	0.898
Adjusted R Square	0.881
Standard Error	1839.311
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	179340359.2	179340359.2	53.01120495	0.00034182
Residual	6	20298390.8	3383065.134		
Total	7	199638750			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	18464.37	3477.57	5.31	0.00	9955.06	26973.68	9955.06	26973.68
X Variable 1	4060.92	557.75	7.28	0.00	2696.15	5425.69	2696.15	5425.69

Multiple Regression

Study the relationship of demand to two or more independent variables

$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots + \beta_k x_k$

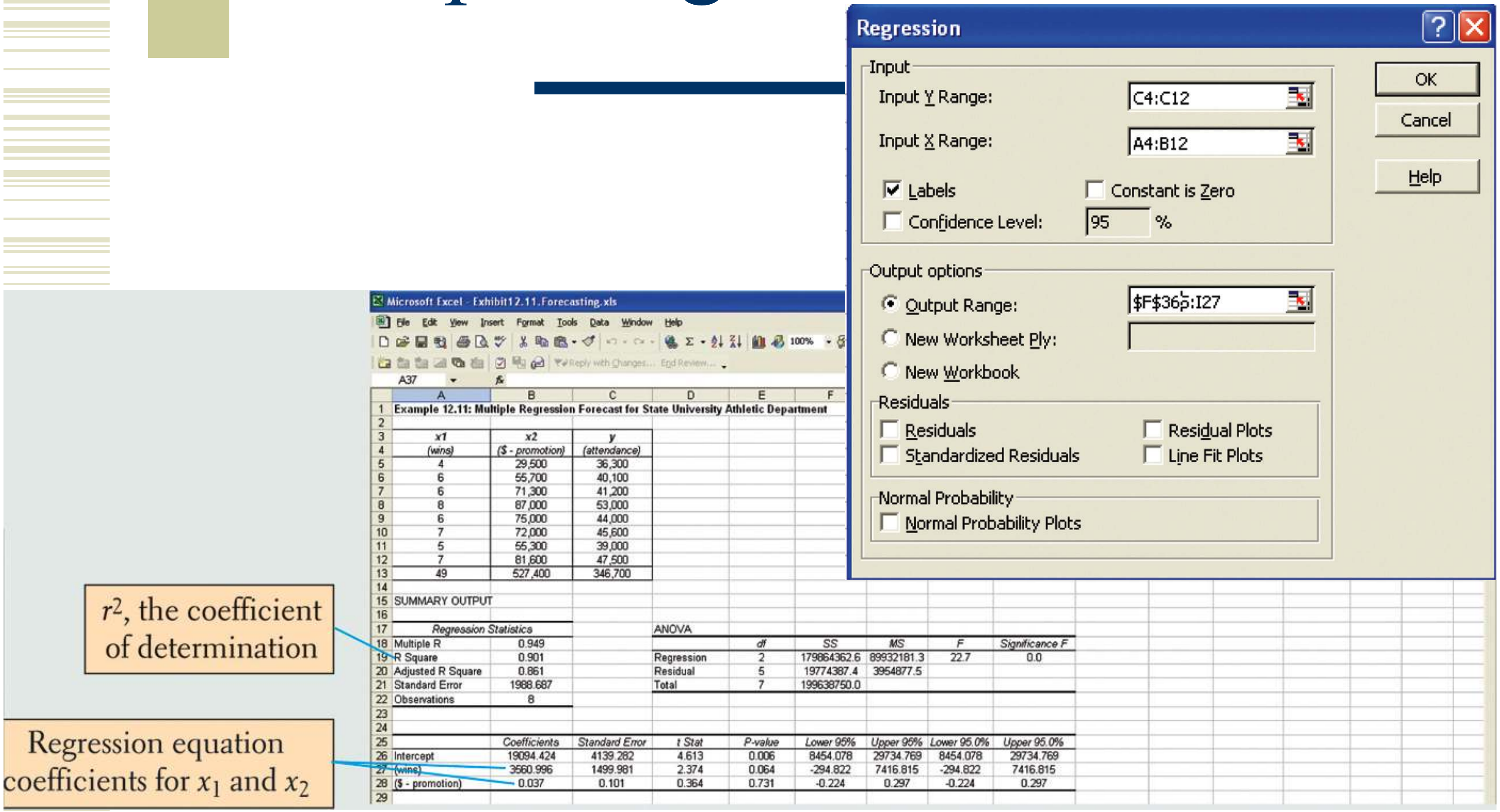
where

β_0 = the intercept

$\beta_1, \ldots, \beta_k$ = parameters for the independent variables

$x_1, \ldots, x_k$ = independent variables

Multiple Regression with Excel



x1 (wins)	x2 ($ - promotion)	y (attendance)
4	29,500	36,300
6	55,700	40,100
6	71,300	41,200
8	87,000	53,000
6	75,000	44,000
7	72,000	45,600
5	55,300	39,000
7	81,600	47,500
49	527,400	346,700

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.949
R Square	0.901
Adjusted R Square	0.861
Standard Error	1988.687
Observations	8

ANOVA

	df	SS	MS	F	Significance F
Regression	2	179864362.6	89932181.3	22.7	0.0
Residual	5	19774387.4	3954877.5		
Total	7	199638750.0			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	19094.424	4139.282	4.613	0.006	8454.078	29734.769	8454.078	29734.769
(wins)	3560.996	1499.981	2.374	0.064	-294.822	7416.815	-294.822	7416.815
($ - promotion)	0.037	0.101	0.364	0.731	-0.224	0.297	-0.224	0.297