Contents

Preface ..... **vii**

Acknowledgments ..... **ix**

Chapter 1 Overview of Time Series **1**

1.1 Introduction 1

1.2 Analysis Methods and SAS/ETS Software 2
1.2.1 Options 2
1.2.2 How SAS/ETS Software Procedures Interrelate 4

1.3 Simple Models: Regression 6
1.3.1 Linear Regression 6
1.3.2 Highly Regular Seasonality 13
1.3.3 Regression with Transformed Data 21

Chapter 2 Simple Models: Autoregression **27**

2.1 Introduction 27
2.1.1 Terminology and Notation 27
2.2.2 Statistical Background 28

2.2 Forecasting 29
2.2.1 Forecasting with PROC ARIMA 30
2.2.2 Backshift Notation B for Time Series 40
2.2.3 Yule-Walker Equations for Covariances 41

2.3 Fitting an AR Model in PROC REG 45

Chapter 3 The General ARIMA Model **49**

3.1 Introduction 49
3.1.1 Statistical Background 49
3.1.2 Terminology and Notation 50

3.2 Prediction 51
3.2.1 One-Step-Ahead Predictions 51
3.2.2 Future Predictions 52

3.3 Model Identification 55
3.3.1 Stationarity and Invertibility 55
3.3.2 Time Series Identification 56
3.3.3 Chi-Squared Check of Residuals 79
3.3.4 Summary of Model Identification 79

3.4 Examples and Instructions 80
3.4.1 IDENTIFY Statement for Series 1-8 81
3.4.2 Example: Iron and Steel Export Analysis 90
3.4.3 Estimation Methods Used in PROC ARIMA 95
3.4.4 ESTIMATE Statement for Series 8 97
3.4.5 Nonstationary Series 102
3.4.6 Effect of Differencing on Forecasts 104
3.4.7 Examples: Forecasting IBM Series and Silver Series 105
3.4.8 Models for Nonstationary Data 113
3.4.9 Differencing to Remove a Linear Trend 123
3.4.10 Other Identification Techniques 128

Chapter 4 The ARIMA Model: Introductory Applications 143

4.1 Seasonal Time Series 143
4.1.1 Introduction to Seasonal Modeling 143
4.1.2 Model Identification 145

4.2 Models with Explanatory Variables 164
4.2.1 Case 1: Regression with Time Series Errors 164
4.2.2 Case 1A: Intervention 165
4.2.3 Case 2: Simple Transfer Function 165
4.2.4 Case 3: General Transfer Function 166
4.2.5 Case 3A: Leading Indicators 166
4.2.6 Case 3B: Intervention 167

4.3 Methodology and Example 167
4.3.1 Case 1: Regression with Time Series Errors 167
4.3.2 Case 2: Simple Transfer Functions 179
4.3.3 Case 3: General Transfer Functions 183
4.3.4 Case 3B: Intervention 213

4.4 Further Examples 223
4.4.1 North Carolina Retail Sales 223
4.4.2 Construction Series Revisited 231
4.4.3 Milk Scare (Intervention) 233
4.4.4 Terrorist Attack 237

Chapter 5 The ARIMA Model: Special Applications 239

5.1 Regression with Time Series Errors and Unequal Variances 239
5.1.1 Autoregressive Errors 239
5.1.2 Example: Energy Demand at a University 241
5.1.3 Unequal Variances 245
5.1.4 ARCH, GARCH, and IGARCH for Unequal Variances 249

5.2 Cointegration 256
5.2.1 Introduction 256
5.2.2 Cointegration and Eigenvalues 258
5.2.3 Impulse Response Function 258
5.2.4 Roots in Higher-Order Models 260
5.2.5 Cointegration and Unit Roots 263

5.2.6 An Illustrative Example 265
5.2.7 Estimating the Cointegrating Vector 270
5.2.8 Intercepts and More Lags 273
5.2.9 PROC VARMAX 275
5.2.10 Interpreting the Estimates 277
5.2.11 Diagnostics and Forecasts 279

Chapter 6 State Space Modeling 283

6.1 Introduction 283
6.1.1 Some Simple Univariate Examples 283
6.1.2 A Simple Multivariate Example 285
6.1.3 Equivalence of Statespace and Vector ARMA Models 294

6.2 More Examples 298
6.2.1 Some Univariate Examples 298
6.2.2 ARMA(1,1) of Dimension 301

6.3 PROC STATESPACE 302
6.3.1 State Vectors Determined from Covariances 305
6.3.2 Canonical Correlations 305
6.3.3 Simulated Example 307

Chapter 7 Spectral Analysis 323

7.1 Periodic Data: Introduction 323

7.2 Example: Plant Enzyme Activity 324

7.3 PROC SPECTRA Introduced 326

7.4 Testing for White Noise 328

7.5 Harmonic Frequencies 330

7.6 Extremely Fast Fluctuations and Aliasing 334

7.7 The Spectral Density 335

7.8 Some Mathematical Detail (Optional Reading) 339

7.9 Estimating the Spectrum: The Smoothed Periodogram 340

7.10 Cross Spectral Analysis 341
7.10.1 Interpreting Cross-Spectral Quantities 341
7.10.2 Interpreting Cross-Amplitude and Phase Spectra 344
7.10.3 PROC SPECTRA Statements 346
7.10.4 Cross-Spectral Analysis of the Neuse River Data 350
7.10.5 Details on Gain, Phase, and Pure Delay 354

Chapter 8 Data Mining and Forecasting 359

8.1 Introduction 359

8.2 Forecasting Data Model 360

8.3 The Time Series Forecasting System 362

8.4 HPF Procedure 368
8.5 Scorecard Development 375
8.6 Business Goal Performance Metrics 376
8.7 Graphical Displays 376
8.8 Goal-Seeking Model Development 381
8.9 Summary 383

References **385**

Index **389**