

Contents

Preface	vii
1 Introduction	1
1.1 Examples of Time Series	1
1.2 Objectives of Time Series Analysis	9
1.3 Linear Time Series Models	10
1.3.1 White Noise Processes	10
1.3.2 AR Models	10
1.3.3 MA Models	12
1.3.4 ARMA Models	12
1.3.5 ARIMA Models	13
1.4 What Is a Nonlinear Time Series?	14
1.5 Nonlinear Time Series Models	16
1.5.1 A Simple Example	16
1.5.2 ARCH Models	17
1.5.3 Threshold Models	18
1.5.4 Nonparametric Autoregressive Models	18
1.6 From Linear to Nonlinear Models	20
1.6.1 Local Linear Modeling	20
1.6.2 Global Spline Approximation	23
1.6.3 Goodness-of-Fit Tests	24
1.7 Further Reading	25
1.8 Software Implementations	27

2	Characteristics of Time Series	29
2.1	Stationarity	29
2.1.1	Definition	29
2.1.2	Stationary ARMA Processes	30
2.1.3	Stationary Gaussian Processes	32
2.1.4	Ergodic Nonlinear Models*	33
2.1.5	Stationary ARCH Processes	37
2.2	Autocorrelation	38
2.2.1	Autocovariance and Autocorrelation	39
2.2.2	Estimation of ACVF and ACF	41
2.2.3	Partial Autocorrelation	43
2.2.4	ACF Plots, PACF Plots, and Examples	45
2.3	Spectral Distributions	48
2.3.1	Periodic Processes	49
2.3.2	Spectral Densities	51
2.3.3	Linear Filters	55
2.4	Periodogram	60
2.4.1	Discrete Fourier Transforms	60
2.4.2	Periodogram	62
2.5	Long-Memory Processes*	64
2.5.1	Fractionally Integrated Noise	65
2.5.2	Fractionally Integrated ARMA processes	66
2.6	Mixing*	67
2.6.1	Mixing Conditions	68
2.6.2	Inequalities	71
2.6.3	Limit Theorems for α -Mixing Processes	74
2.6.4	A Central Limit Theorem for Nonparametric Regression	76
2.7	Complements	78
2.7.1	Proof of Theorem 2.5(i)	78
2.7.2	Proof of Proposition 2.3(i)	79
2.7.3	Proof of Theorem 2.9	79
2.7.4	Proof of Theorem 2.10	80
2.7.5	Proof of Theorem 2.13	81
2.7.6	Proof of Theorem 2.14	81
2.7.7	Proof of Theorem 2.22	84
2.8	Additional Bibliographical Notes	87
3	ARMA Modeling and Forecasting	89
3.1	Models and Background	89
3.2	The Best Linear Prediction—Prewhitening	91
3.3	Maximum Likelihood Estimation	93
3.3.1	Estimators	93
3.3.2	Asymptotic Properties	97
3.3.3	Confidence Intervals	99

3.4	Order Determination	99
3.4.1	Akaike Information Criterion	100
3.4.2	FPE Criterion for AR Modeling	102
3.4.3	Bayesian Information Criterion	103
3.4.4	Model Identification	104
3.5	Diagnostic Checking	110
3.5.1	Standardized Residuals	110
3.5.2	Visual Diagnostic	110
3.5.3	Tests for Whiteness	111
3.6	A Real Data Example—Analyzing German Egg Prices . . .	113
3.7	Linear Forecasting	117
3.7.1	The Least Squares Predictors	117
3.7.2	Forecasting in AR Processes	118
3.7.3	Mean Squared Predictive Errors for AR Processes . .	119
3.7.4	Forecasting in ARMA Processes	120
4	Parametric Nonlinear Time Series Models	125
4.1	Threshold Models	125
4.1.1	Threshold Autoregressive Models	126
4.1.2	Estimation and Model Identification	131
4.1.3	Tests for Linearity	134
4.1.4	Case Studies with Canadian Lynx Data	136
4.2	ARCH and GARCH Models	143
4.2.1	Basic Properties of ARCH Processes	143
4.2.2	Basic Properties of GARCH Processes	147
4.2.3	Estimation	156
4.2.4	Asymptotic Properties of Conditional MLEs*	161
4.2.5	Bootstrap Confidence Intervals	163
4.2.6	Testing for the ARCH Effect	165
4.2.7	ARCH Modeling of Financial Data	168
4.2.8	A Numerical Example: Modeling S&P 500 Index Re- turns	171
4.2.9	Stochastic Volatility Models	179
4.3	Bilinear Models	181
4.3.1	A Simple Example	182
4.3.2	Markovian Representation	184
4.3.3	Probabilistic Properties*	185
4.3.4	Maximum Likelihood Estimation	189
4.3.5	Bispectrum	189
4.4	Additional Bibliographical notes	191
5	Nonparametric Density Estimation	193
5.1	Introduction	193
5.2	Kernel Density Estimation	194
5.3	Windowing and Whitening	197

5.4	Bandwidth Selection	199
5.5	Boundary Correction	202
5.6	Asymptotic Results*	204
5.7	Complements—Proof of Theorem 5.3	211
5.8	Bibliographical Notes	212
6	Smoothing in Time Series	215
6.1	Introduction	215
6.2	Smoothing in the Time Domain	215
6.2.1	Trend and Seasonal Components	215
6.2.2	Moving Averages	217
6.2.3	Kernel Smoothing	218
6.2.4	Variations of Kernel Smoothers	220
6.2.5	Filtering	221
6.2.6	Local Linear Smoothing	222
6.2.7	Other Smoothing Methods	224
6.2.8	Seasonal Adjustments	224
6.2.9	Theoretical Aspects*	225
6.3	Smoothing in the State Domain	228
6.3.1	Nonparametric Autoregression	228
6.3.2	Local Polynomial Fitting	230
6.3.3	Properties of the Local Polynomial Estimator	234
6.3.4	Standard Errors and Estimated Bias	241
6.3.5	Bandwidth Selection	243
6.4	Spline Methods	246
6.4.1	Polynomial Splines	247
6.4.2	Nonquadratic Penalized Splines	249
6.4.3	Smoothing Splines	251
6.5	Estimation of Conditional Densities	253
6.5.1	Methods of Estimation	253
6.5.2	Asymptotic Properties*	256
6.6	Complements	257
6.6.1	Proof of Theorem 6.1	257
6.6.2	Conditions and Proof of Theorem 6.3	260
6.6.3	Proof of Lemma 6.1	266
6.6.4	Proof of Theorem 6.5	268
6.6.5	Proof for Theorems 6.6 and 6.7	269
6.7	Bibliographical Notes	271
7	Spectral Density Estimation and Its Applications	275
7.1	Introduction	275
7.2	Tapering, Kernel Estimation, and Prewhitening	276
7.2.1	Tapering	277
7.2.2	Smoothing the Periodogram	281
7.2.3	Prewhitening and Bias Reduction	282

7.3	Automatic Estimation of Spectral Density	283
7.3.1	Least-Squares Estimators and Bandwidth Selection	284
7.3.2	Local Maximum Likelihood Estimator	286
7.3.3	Confidence Intervals	289
7.4	Tests for White Noise	296
7.4.1	Fisher's Test	296
7.4.2	Generalized Likelihood Ratio Test	298
7.4.3	χ^2 -Test and the Adaptive Neyman Test	300
7.4.4	Other Smoothing-Based Tests	302
7.4.5	Numerical Examples	303
7.5	Complements	304
7.5.1	Conditions for Theorems 7.1—7.3	304
7.5.2	Lemmas	305
7.5.3	Proof of Theorem 7.1	306
7.5.4	Proof of Theorem 7.2	307
7.5.5	Proof of Theorem 7.3	307
7.6	Bibliographical Notes	310
8	Nonparametric Models	313
8.1	Introduction	313
8.2	Multivariate Local Polynomial Regression	314
8.2.1	Multivariate Kernel Functions	314
8.2.2	Multivariate Local Linear Regression	316
8.2.3	Multivariate Local Quadratic Regression	317
8.3	Functional-Coefficient Autoregressive Model	318
8.3.1	The Model	318
8.3.2	Relation to Stochastic Regression	318
8.3.3	Ergodicity*	319
8.3.4	Estimation of Coefficient Functions	321
8.3.5	Selection of Bandwidth and Model-Dependent Variable	322
8.3.6	Prediction	324
8.3.7	Examples	324
8.3.8	Sampling Properties*	332
8.4	Adaptive Functional-Coefficient Autoregressive Models	333
8.4.1	The Models	334
8.4.2	Existence and Identifiability	335
8.4.3	Profile Least-Squares Estimation	337
8.4.4	Bandwidth Selection	340
8.4.5	Variable Selection	340
8.4.6	Implementation	341
8.4.7	Examples	343
8.4.8	Extensions	349
8.5	Additive Models	349
8.5.1	The Models	349
8.5.2	The Backfitting Algorithm	350

8.5.3	Projections and Average Surface Estimators	352
8.5.4	Estimability of Coefficient Functions	354
8.5.5	Bandwidth Selection	355
8.5.6	Examples	356
8.6	Other Nonparametric Models	364
8.6.1	Two-Term Interaction Models	365
8.6.2	Partially Linear Models	366
8.6.3	Single-Index Models	367
8.6.4	Multiple-Index Models	368
8.6.5	An Analysis of Environmental Data	371
8.7	Modeling Conditional Variance	374
8.7.1	Methods of Estimating Conditional Variance	375
8.7.2	Univariate Setting	376
8.7.3	Functional-Coefficient Models	382
8.7.4	Additive Models	382
8.7.5	Product Models	384
8.7.6	Other Nonparametric Models	384
8.8	Complements	384
8.8.1	Proof of Theorem 8.1	384
8.8.2	Technical Conditions for Theorems 8.2 and 8.3	386
8.8.3	Preliminaries to the Proof of Theorem 8.3	387
8.8.4	Proof of Theorem 8.3	390
8.8.5	Proof of Theorem 8.4	392
8.8.6	Conditions of Theorem 8.5	394
8.8.7	Proof of Theorem 8.5	395
8.9	Bibliographical Notes	399
9	Model Validation	405
9.1	Introduction	405
9.2	Generalized Likelihood Ratio Tests	406
9.2.1	Introduction	406
9.2.2	Generalized Likelihood Ratio Test	408
9.2.3	Null Distributions and the Bootstrap	409
9.2.4	Power of the GLR Test	414
9.2.5	Bias Reduction	414
9.2.6	Nonparametric versus Nonparametric Models	415
9.2.7	Choice of Bandwidth	416
9.2.8	A Numerical Example	417
9.3	Tests on Spectral Densities	419
9.3.1	Relation with Nonparametric Regression	421
9.3.2	Generalized Likelihood Ratio Tests	421
9.3.3	Other Nonparametric Methods	425
9.3.4	Tests Based on Rescaled Periodogram	427
9.4	Autoregressive versus Nonparametric Models	430
9.4.1	Functional-Coefficient Alternatives	430

9.4.2	Additive Alternatives	434
9.5	Threshold Models versus Varying-Coefficient Models	437
9.6	Bibliographical Notes	439
10	Nonlinear Prediction	441
10.1	Features of Nonlinear Prediction	441
10.1.1	Decomposition for Mean Square Predictive Errors .	441
10.1.2	Noise Amplification	444
10.1.3	Sensitivity to Initial Values	445
10.1.4	Multiple-Step Prediction versus a One-Step Plug-in Method	447
10.1.5	Nonlinear versus Linear Prediction	448
10.2	Point Prediction	450
10.2.1	Local Linear Predictors	450
10.2.2	An Example	451
10.3	Estimating Predictive Distributions	454
10.3.1	Local Logistic Estimator	455
10.3.2	Adjusted Nadaraya–Watson Estimator	456
10.3.3	Bootstrap Bandwidth Selection	457
10.3.4	Numerical Examples	458
10.3.5	Asymptotic Properties	463
10.3.6	Sensitivity to Initial Values: A Conditional Distribu- tion Approach	466
10.4	Interval Predictors and Predictive Sets	470
10.4.1	Minimum-Length Predictive Sets	471
10.4.2	Estimation of Minimum-Length Predictors	474
10.4.3	Numerical Examples	476
10.5	Complements	482
10.6	Additional Bibliographical Notes	485
	References	487
	Author index	537
	Subject index	545