## **Contents**

List of Figures	ix	2.1.2 Stationarity 42
List of Tables	xiii	2.1.3 Sample Autocorrelations
Preface	XV	and Sample Partial Autocorrelations 45
		2.2 Moving Average and Autoregressive
		Processes 49
1 Lineau Democrieus Mandal	1	2.2.1 Finite Order Moving Average
1. Linear Regression Model	1	Processes 49
1.1 Inference in Linear Regression Models	1	2.2.2 Autoregressive Processes 52
1.1.1 The Ordinary Least Squares Estimator	3	2.2.3 Autoregressive Moving Average
1.1.2 Goodness of Fit Measures	5	Processes 58
1.1.3 The Generalized Least Squared		2.3 Selection and Estimation of AR, MA,
Estimator	7	and ARMA Models 6
1.1.4 Maximum Likelihood Estimator	9	2.3.1 The Selection of the Model
1.1.5 Hypotheses Testing, Confidence		and the Role of Information
Intervals, and Predictive Intervals	10	Criteria 6
1.1.6 Linear Regression Model With		2.3.2 Estimation Methods 65
Stochastic Regressors	15	2.3.3 Residual Diagnostics 65
1.1.7 Asymptotic Theory for Linear		2.4 Forecasting ARMA Processes 7
Regressions	16	2.4.1 Standard Principles of Forecasting 7
1.2 Testing for Violations of the Linear	142	2.4.2 Forecasting an AR(p) Process 7
Regression Framework	18	2.4.3 Forecasting the Future Value
1.2.1 Linearity	18	of an $MA(q)$ Process 72
1.2.2 Structural Breaks and Parameter	255	2.4.4 Evaluating the Accuracy
Stability Test	23	of a Forecast Function 73
1.3 Specifying the Regressors	25	References 75
1.3.1 How to Select the Regressors	26	Appendix 2.A
1.3.2 Multicollinearity	29	
1.3.3 Measurement Errors in the Regressors	31	
1.4 Issues With Heteroskedasticity and	20	
Autocorrelation of the Errors	32	3. Vector Autoregressive Moving
1.4.1 Heteroskedastic Errors	32	Average (VARMA) Models 77
1.4.2 Autocorrelated Errors	34 34	3.1 Foundations of Multivariate Time Series
1.5 The Interpretation of Regression Results References	36	Analysis 77
Appendix 1.A	36	3.1.1 Weak Stationarity of Multivariate
Appendix 1.B Principal Component Analysis	38	Time Series 72
represent the removed component remarkation	50	3.1.2 Cross-Covariance
		and Cross-Correlation Matrices 78
		3.1.3 Sample Cross-Covariance
2. Autoregressive Moving Average		and Cross-Correlation Matrices 79
(ARMA) Models and Their Practical		3.1.4 Multivariate Portmanteau Tests 81
Applications	41	3.1.5 Multivariate White Noise Process 82
2.1 Essential Concepts in Time Series Analysis	41	3.2 Introduction to Vector Autoregressive
2.1.1 Time Series and Their Properties	41	Analysis 82

		3.2.1	From Structural to Reduced-Form	2020	5	. Sir	igle-l	Factor Conditionally	
		2 2 2	Vector Autoregressive Models	82		He	teros	skedastic Models, ÁRCH	
		3.2.2	Stationarity Conditions and				d GA		151
			the Population Moments					zed Facts and Preliminaries	151
		2 2 2	of a VAR(1) Process	86				The Stylized Facts of Conditional	131
		3.2.3	Generalization to a VAR(p) Model	89			J.,,,,	Heteroskedasticity	153
			Estimation of a VAR(p) Model	91		5.2	Simp	le Univariate Parametric Models	157
		3.2.5	Specification of a Vector			200		Rolling Window Forecasts	157
			Autoregressive Model					Exponential Smoothing Variance	137
			and Hypothesis Testing	94			0.2.12	Forecasts: RiskMetrics	160
		3.2.6	Forecasting With a Vector				523	ARCH Models	161
	2.2	C.	Autoregressive Model	97				Comparing the Performance	101
	3.3		tural Analysis With Vector	34927400			0.2.1	of Alternative Variance Forecast	
			regressive Models	100				Models: Do We Need More Than	
		2.2.1	Impulse Response Functions	100				ARCH?	168
			Variance Decompositions	105			525	Generalized ARCH Models	100
	2.4		Granger Causality	108			3.2.3	and Their Statistical Properties	171
	3.4		or Moving Average and Vector	440			526	A Few Additional, Popular ARCH	171
			regressive Moving Average Models	110			3.2.0	Models	101
		3.4.1	Vector Moving Average Models	110		5.3	Adva	nced Univariate Volatility Modeling	181 190
		3.4.2	Vector Autoregressive Moving	4.4.4		0.0		Non-Gaussian Marginal	190
	Ref	erence:	Average Models	111			5.5.1	Innovations	100
	IXC1	CI CIICC.	•	112			532	GARCH Models Augmented by	190
							3.3.2	Exogenous (Predetermined) Factors	107
						5.4	Testin	ig for ARCH	197 <b>198</b>
1.	Un	it Roc	ots and Cointegration	113		0		Lagrange Multiplier ARCH Tests	199
	4.1	Defin	ing Unit Root Processes	113				News Impact Curves and Testing	199
			What Happens If One Incorrectly				J	for Asymmetric ARCH	202
			Detrends a Unit Root Series?	118		5.5	Forec	asting With GARCH Models	202
		4.1.2	What Happens If One Incorrectly					Long-Horizon, Point Forecasts	206
			Applies Differencing					Forecasts of Variance for Sums	200
			to (Deterministic) Trend-Stationary				0.01	of Returns or Shocks	208
			Series?	119		5.6	Estima	ation of and Inference on GARCH	200
		4.1.3	What Happens If One Incorrectly	,			Mode		210
			Applies Differencing to a Stationary				5.6.1	Maximum Likelihood Estimation	212
			Series?	120				The Properties of MLE	214
		4.1.4	What Happens If One Incorrectly	0				Quasi MLE	218
			Applies Differencing $d + r$ Times					Misspecification Tests	221
			to an I(d) Series?	121				Sequential Estimation and QMLE	221
	4.2	The Sp	ourious Regression Problem	121				Data Frequency in Estimation	
	4.3	Unit R	oot Tests	124				and Temporal Aggregation	223
		4.3.1	Classical Dickey-Fuller Tests	124		Refe	rences		225
			The Augmented Dickey-Fuller Test	126		Appe	endix 5	5.A Nonparametric Kernel	- 17 <del>1</del> (03)=31
			Other Unit Root Tests	131		Dens	sity Est	timation	226
		4.3.4	Testing for Unit Roots	020000					
			in Moving-Average Processes	132					
	4.4	Cointe	gration and Error-Correction		6	Adeal	tivori	iate GARCH and	
		Model	s	133	U.				000
		4.4.1	The Relationship Between					nal Correlation Models	229
			Cointegration and Economic Theory	133				uction and Preliminaries	229
			Definition of Cointegration	134		0.2	Simple	Models of Covariance	222
			Error-Correction Models	135			Predic		230
	1776 - 201		Testing for Cointegration	138				Multivariate GARCH Models ant and Dynamic Conditional	238
	Refe	rences		149				ation Models	250

	<ul><li>6.5 Factor GARCH Models</li><li>6.6 Inference and Model Specification</li><li>References</li></ul>	257 264 266	8.3.3 Testing (Non-)Linearities References	322 <b>326</b>
			4.	
,	Multifactor Hotorockadastic Madala		9. Markov Switching Models	329
٠	Multifactor Heteroskedastic Models,	United States	9.1 Definitions and Classifications	329
	Stochastic Volatility	267	9.2 Understanding Markov Switching	~~=
	7.1 A Primer on the Kalman Filter 7.1.1 A Simple Univariate Example	268	Dynamics Through Simulations	337
	7.1.2 The General Case	268 270	9.2.1 Markov Switching Models	
	7.2 Simple Stochastic Volatility Models	270	as Normal Mixtures and Density Approximation	340
	and their Estimation Using the Kalman		9.3 Markov Switching Regressions	341
	Filter	271	9.4 Markov Chain Processes and Their	
	7.2.1 The Economics of Stochastic		Properties	344
	Volatility: The Normal Mixture		9.5 Estimation and Inference for Markov	250
	Model	271	Switching Models	350
	7.2.2 One Benchmark Case:		9.5.1 Maximum Likelihood Estimation and the Expectation-Maximization	
	The Log-Normal Two-Factor Stochastic Volatility Model	272	Algorithm	350
	7.3 Extended, Second-Generation Stochastic		9.5.2 Tests of Hypotheses	359
	Volatility Models	281	9.5.3 Testing and Selecting the Number	
	7.4 GARCH versus Stochastic Volatility:		of Regimes and the Nuisance	
	Which One?	282	Parameters Problem	362
	7.4.1 Some GARCH Models Are		9.6 Forecasting With Markov Switching	0.58
	(Asymptotically) Stochastic Volatility Models	282	Models 9.7 Markov Switching ARCH and DCC	365
	7.4.2 Stressing the Differences:	202	Models	369
	What Have We Learned So Far?	284	9.8 Do Nonlinear and Markov Switching	000
	References	285	Models Work in Practice?	372
			References	374
			Appendix 9.A Some Notions Concerning Ergodic Markov Chains	376
	. Models With Breaks, Recurrent		Appendix 9.B State-Space Representation	3/0
	Regime Switching, and		of an Markov Switching Model	377
	Nonlinearities	287	Appendix 9.C First-Order Conditions	
	8.1 A Primer on the Key Features		for Maximum Likelihood Estimation	0.70
	and Classification of Statistical Model		of Markov Switching Models	378
	of Instability	287		
	8.2 Detecting and Exploiting Structural Change in Linear Models	290		
	8.2.1 Chow Tests for Given Break Dates	291	10. Realized Volatility and Covariance	381
	8.2.2 CUSUM and CUSUM Square Tests	293	10.1 Measuring Realized Variance	381
	8.2.3 Andrews and Quandt's Single-Break		10.1.1 Quadratic Variation	
	Test	294	and Its Estimators	381
	8.2.4 Bai and Perron's Multiple,		10.1.2 Microstructure Noise	
	Endogenous Breaks Test	297	and the Choice of the Sampling	
	8.2.5 Testing for Breaks When Testing		Frequency	383
	for Unit Roots and Cointegration,	0.00	10.1.3 Other Bias-Adjusted Measures of Realized Volatility	205
	and Vice Versa	302	10.1.4 Jumps and Bipower Variation	385 387
	8.3 Threshold and Smooth Transition Regime Switching Models	307	10.2 Forecasting Realized Variance	388
	8.3.1 Threshold Regression	50,	10.2.1 Stylized Facts About Realized	15 15 15
	and Autoregressive Models	308	Variance	388
	8.3.2 Smooth Transition Regression		10.2.2 Forecasting Realized Variance:	
	and Autoregressive Models	316	Heterogeneous Autoregressions	390

## Contents

10.2.3	Range-Based Variance Forecasts	392	Appendix A: Mathematical and Statistical Appendix	399
10.3 Multiva	riate Applications	395		
10.3.1	Realized Covariance Matrix		La de la companya de	409
	Estimation	395	Index	409
10.3.2	Range-Based Covariance			
	Estimation	396		
References		396		