

Contents

1	Introduction	<i>page</i> 1
	1.1 Overview	1
	1.2 Birth of the text	2
	1.3 Who will benefit	3
	1.4 Why this book is relevant	3
	1.5 Examples	4
	1.5.1 CO ₂ emissions	4
	1.5.2 Age earnings	5
	1.5.3 Hedonic price function	6
	1.6 Examples in the text	7
	1.6.1 Density	8
	1.6.2 Regression	9
	1.7 Outline of the remainder of the book	9
	1.8 Supplemental materials	11
	1.9 Acknowledgments	12
2	Univariate density estimation	15
	2.1 Smoothing preliminaries	16
	2.2 Estimation	19
	2.2.1 A crude estimator	19
	2.2.2 Naïve estimator	22
	2.2.3 Kernel estimator	24
	2.3 Kernel selection	28
	2.4 Kernel efficiency	29
	2.5 Bandwidth selection	30
	2.5.1 Optimal selection	30
	2.5.2 Data-driven methods	33
	2.5.3 Plug-in or cross-validation?	43
	2.6 Density derivatives	45
	2.6.1 Bias and variance	47
	2.6.2 Bandwidth selection	48
	2.6.3 Relative efficiency	50
	2.7 Application	50
	2.7.1 Histograms	51
	2.7.2 Kernel densities	52

3	Multivariate density estimation	59
3.1	Joint densities	59
3.2	Bias, variance, and AMISE	62
3.3	The curse of dimensionality	64
3.4	Bandwidth selection	68
3.4.1	Rule-of-thumb bandwidth selection	70
3.4.2	Cross-validation bandwidth selection	70
3.5	Conditional density estimation	72
3.5.1	Bias, variance, and AMSE	73
3.5.2	Bandwidth selection	74
3.5.3	Inclusion of irrelevant variables	75
3.6	Application	76
4	Inference about the density	83
4.1	Fundamentals	84
4.1.1	Consistent test	86
4.1.2	Distance measures	87
4.1.3	Centering terms	89
4.1.4	Degenerate U-statistics	89
4.1.5	Bootstrap	91
4.2	Equality	92
4.3	Parametric specification	97
4.4	Independence	99
4.5	Symmetry	101
4.6	Silverman test for multimodality	102
4.7	Testing in practice	105
4.7.1	Bootstrap versus asymptotic distribution	106
4.7.2	Role of bandwidth selection on reliability of tests	106
4.8	Application	108
4.8.1	Equality	108
4.8.2	Correct parametric specification	109
4.8.3	Independence	110
4.8.4	Symmetry	111
4.8.5	Modality	112
5	Regression	113
5.1	Smoothing preliminaries	114
5.2	Local-constant estimator	117
5.2.1	Derivation from density estimators	117
5.2.2	An indicator approach	118
5.2.3	Kernel regression on a constant	118
5.3	Bias, variance, and AMISE of the LCLS estimator	120
5.4	Bandwidth selection	121
5.4.1	Univariate digression	121
5.4.2	Optimal bandwidths in higher dimensions	123
5.4.3	Least-squares cross-validation	124

<i>Contents</i>		ix
5.4.4	Cross-validation based on Akaike information criteria	125
5.4.5	Interpretation of bandwidths for LCLS	126
5.5	Gradient estimation	127
5.6	Limitations of LCLS	128
5.7	Local-linear estimation	130
5.7.1	Choosing LLLS over LCLS	131
5.7.2	Efficiency of the local-linear estimator	132
5.8	Local-polynomial estimation	133
5.9	Gradient-based bandwidth selection	135
5.10	Standard errors and confidence bounds	137
5.10.1	Pairs bootstrap	137
5.10.2	Residual bootstrap	138
5.10.3	Wild bootstrap	139
5.11	Displaying estimates	139
5.12	Assessing fit	141
5.13	Prediction	141
5.14	Application	142
5.14.1	Data	143
5.14.2	Results	144
6	Testing in regression	159
6.1	Testing preliminaries	160
6.1.1	Goodness-of-fit tests	160
6.1.2	Conditional-moment test	161
6.2	Correct parametric specification	162
6.2.1	Goodness-of-fit test	163
6.2.2	Conditional-moment test	166
6.3	Irrelevant regressors	168
6.3.1	Goodness-of-fit test	168
6.3.2	Conditional-moment test	169
6.4	Heteroskedasticity	171
6.5	Testing in practice	174
6.5.1	Bootstrap versus asymptotic distribution	174
6.5.2	Role of bandwidth selection on reliability of tests	175
6.6	Application	177
6.6.1	Correct functional form	177
6.6.2	Relevance	180
6.6.3	Heteroskedasticity	180
6.6.4	Density tests	182
7	Smoothing discrete variables	187
7.1	Estimation of a density	188
7.1.1	Kernels for smoothing discrete variables	188
7.1.2	Generalized product kernel	190
7.2	Finite sample properties	191
7.2.1	Discrete-only bias	191

7.2.2	Discrete-only variance	192
7.2.3	Discrete-only MSE	192
7.2.4	Mixed-data bias	193
7.2.5	Mixed-data variance	193
7.2.6	Mixed-data MSE	193
7.3	Bandwidth estimation	194
7.3.1	Discrete-data only	195
7.3.2	Mixed data	196
7.4	Why the faster rate of convergence?	197
7.5	Alternative discrete kernels	198
7.6	Testing	199
7.7	Application	201
8	Regression with discrete covariates	205
8.1	Estimation of the conditional mean	206
8.1.1	Local-constant least-squares	206
8.1.2	Local-linear least-squares	208
8.2	Estimation of gradients	209
8.2.1	Continuous covariates	209
8.2.2	Discrete covariates	210
8.3	Bandwidth selection	212
8.3.1	Automatic bandwidth selection	213
8.3.2	Upper and lower bounds for discrete bandwidths	214
8.4	Testing	215
8.4.1	Correct parametric specification	215
8.4.2	Significance of continuous regressors	216
8.4.3	Significance of discrete regressors	217
8.5	All discrete regressors	220
8.6	Application	222
8.6.1	Bandwidths	222
8.6.2	Elasticities	223
8.6.3	Numerical gradients	223
8.6.4	Testing	225
9	Semiparametric methods	227
9.1	Semiparametric efficiency	228
9.2	Partially linear models	228
9.2.1	Estimation	229
9.2.2	Bandwidth selection	232
9.2.3	Testing	233
9.3	Single-index models	238
9.3.1	Estimation	239
9.3.2	Bandwidth selection	244
9.3.3	Testing	245
9.4	Semiparametric smooth coefficient models	247
9.4.1	Estimation	249

<i>Contents</i>		xi
9.4.2	Bandwidth selection	252
9.4.3	Testing	252
9.5	Additive models	254
9.5.1	Estimation	255
9.5.2	Bandwidth selection	258
9.5.3	Testing	259
9.6	Application	261
9.6.1	Bandwidths	261
9.6.2	Plotting estimates	263
9.6.3	Specification testing	264
10	Instrumental variables	267
10.1	The ill-posed inverse problem	268
10.2	Tackling the ill-posed inverse	270
10.3	Local-polynomial estimation of the control-function model	272
10.3.1	Multiple endogenous regressors	274
10.3.2	Bandwidth selection	275
10.3.3	Choice of polynomial order	276
10.3.4	Simulated evidence of the counterfactual simplification	278
10.3.5	A valid bootstrap procedure	279
10.4	Weak instruments	280
10.4.1	Weak identification	282
10.4.2	Estimation in the presence of weak instruments	284
10.4.3	Importance of nonlinearity in the first stage	286
10.5	Discrete endogenous regressor	286
10.6	Testing	287
10.7	Application	288
11	Panel data	293
11.1	Pooled models	294
11.2	Random effects	295
11.2.1	Local-linear weighted least-squares	297
11.2.2	Wang's iterative estimator	298
11.3	Fixed effects	301
11.3.1	Additive individual effects	302
11.3.2	Discrete individual effects	305
11.4	Dynamic panel estimation	306
11.5	Semiparametric estimators	308
11.6	Bandwidth selection	309
11.7	Standard errors	309
11.7.1	Pairs bootstrap	310
11.7.2	Residual bootstrap	310
11.8	Testing	311
11.8.1	Poolability	311
11.8.2	Functional form specification	313
11.8.3	Nonparametric Hausman test	315

xii	<i>Contents</i>	
	11.9 Application	316
	11.9.1 Bandwidths	317
	11.9.2 Estimation	318
	11.9.3 Testing	318
12	Constrained estimation and inference	321
	12.1 Rearrangement	322
	12.1.1 Imposing convexity	324
	12.1.2 Existing literature	325
	12.2 Motivating alternative shape-constrained estimators	326
	12.3 Implementation methods via reweighting	330
	12.3.1 Constraint-weighted bootstrapping	330
	12.3.2 Data sharpening	330
	12.4 Practical issues	331
	12.4.1 Selecting the distance metric	331
	12.4.2 Choice of smoothing parameter	332
	12.4.3 Linear in p implementation issues	333
	12.4.4 Imposing additive separability	336
	12.5 Hypothesis testing on shape constraints	337
	12.6 Further extensions	338
	12.7 Application	339
	12.7.1 Imposing positive marginal product	339
	12.7.2 Imposing constant returns to scale	340
	<i>Bibliography</i>	343
	<i>Index</i>	359