

Contents

List of tables	xiii
List of figures	xv
Preface to the Revised Third Edition	xix
Preface to the Third Edition	xxi
Preface to the Second Edition	xxiii
Preface to the Revised Edition	xxv
Preface to the First Edition	xxvii
Notation and typography	xxix
1 The problem of survival analysis	1
1.1 Parametric modeling	2
1.2 Semiparametric modeling	2
1.3 Nonparametric analysis	5
1.4 Linking the three approaches	5
2 Describing the distribution of failure times	7
2.1 The survivor and hazard functions	7
2.2 The quantile function	10
2.3 Interpreting the cumulative hazard and hazard rate	13
2.3.1 Interpreting the cumulative hazard	13
2.3.2 Interpreting the hazard rate	15
2.4 Means and medians	16
3 Hazard models	19
3.1 Parametric models	20
3.2 Semiparametric models	21
3.3 Analysis time (time at risk)	24

4 Censoring and truncation	29
4.1 Censoring	29
4.1.1 Right-censoring	30
4.1.2 Interval-censoring	32
4.1.3 Left-censoring	34
4.2 Truncation	34
4.2.1 Left-truncation (delayed entry)	34
4.2.2 Right-truncation	35
4.2.3 Gaps	36
5 Recording survival data	37
5.1 The desired format	37
5.2 Other formats	40
5.3 Example: Wide-form snapshot data	44
6 Using stset	47
6.1 A short lesson on dates	48
6.2 Purposes of the stset command	51
6.3 Syntax of the stset command	51
6.3.1 Specifying analysis time	52
6.3.2 Variables defined by stset	55
6.3.3 Specifying what constitutes failure	57
6.3.4 Specifying when subjects exit from the analysis	59
6.3.5 Specifying when subjects enter the analysis	62
6.3.6 Specifying the subject-ID variable	65
6.3.7 Specifying the begin-of-span variable	67
6.3.8 Convenience options	70
7 After stset	73
7.1 Look at stset's output	73
7.2 List some of your data	76
7.3 Use stdescribe	77
7.4 Use stvary	78

<i>Contents</i>	vii
7.5 Perhaps use stfill	81
7.6 Example: Hip-fracture data	83
8 Nonparametric analysis	91
8.1 Inadequacies of standard univariate methods	91
8.2 The Kaplan–Meier estimator	93
8.2.1 Calculation	93
8.2.2 Censoring	96
8.2.3 Left-truncation (delayed entry)	97
8.2.4 Gaps	99
8.2.5 Relationship to the empirical distribution function	99
8.2.6 Other uses of sts list	101
8.2.7 Graphing the Kaplan–Meier estimate	102
8.3 The Nelson–Aalen estimator	107
8.4 Estimating the hazard function	113
8.5 Estimating mean and median survival times	118
8.6 Tests of hypothesis	122
8.6.1 The log-rank test	123
8.6.2 The Wilcoxon test	125
8.6.3 Other tests	126
8.6.4 Stratified tests	126
9 The Cox proportional hazards model	131
9.1 Using stcox	132
9.1.1 The Cox model has no intercept	133
9.1.2 Interpreting coefficients	133
9.1.3 The effect of units on coefficients	135
9.1.4 Estimating the baseline cumulative hazard and survivor functions	137
9.1.5 Estimating the baseline hazard function	141
9.1.6 The effect of units on the baseline functions	145
9.2 Likelihood calculations	147

9.2.1	No tied failures	147
9.2.2	Tied failures	150
	The marginal calculation	150
	The partial calculation	151
	The Breslow approximation	152
	The Efron approximation	153
9.2.3	Summary	153
9.3	Stratified analysis	155
9.3.1	Obtaining coefficient estimates	155
9.3.2	Obtaining estimates of baseline functions	157
9.4	Cox models with shared frailty	158
9.4.1	Parameter estimation	160
9.4.2	Obtaining estimates of baseline functions	164
9.5	Cox models with survey data	167
9.5.1	Declaring survey characteristics	168
9.5.2	Fitting a Cox model with survey data	169
9.5.3	Some caveats of analyzing survival data from complex survey designs	171
9.6	Cox model with missing data—multiple imputation	172
9.6.1	Imputing missing values	174
9.6.2	Multiple-imputation inference	176
10	Model building using stcox	179
10.1	Indicator variables	179
10.2	Categorical variables	180
10.3	Continuous variables	182
	10.3.1 Fractional polynomials	184
10.4	Interactions	188
10.5	Time-varying variables	191
	10.5.1 Using stcox, tvc(), texp()	193
	10.5.2 Using stsplot	195

10.6	Modeling group effects: fixed-effects, random-effects, stratification, and clustering	199
11	The Cox model: Diagnostics	205
11.1	Testing the proportional-hazards assumption	205
11.1.1	Tests based on reestimation	205
11.1.2	Test based on Schoenfeld residuals	209
11.1.3	Graphical methods	211
11.2	Residuals and diagnostic measures	214
	Reye's syndrome data	215
11.2.1	Determining functional form	216
11.2.2	Goodness of fit	221
11.2.3	Outliers and influential points	225
12	Parametric models	231
12.1	Motivation	231
12.2	Classes of parametric models	234
12.2.1	Parametric proportional hazards models	236
12.2.2	Accelerated failure-time models	241
12.2.3	Comparing the two parameterizations	243
13	A survey of basic parametric regression models in Stata	247
13.1	The exponential model	249
13.1.1	Exponential regression in the PH metric	249
13.1.2	Exponential regression in the AFT metric	256
13.2	Weibull regression	259
13.2.1	Weibull regression in the PH metric	259
	Fitting null models	263
13.2.2	Weibull regression in the AFT metric	267
13.3	Gompertz regression (PH metric)	268
13.4	Lognormal regression (AFT metric)	271
13.5	Loglogistic regression (AFT metric)	275
13.6	Generalized gamma regression (AFT metric)	278

13.7	Choosing among parametric models	280
13.7.1	Nested models	280
13.7.2	Nonnested models	283
14	Postestimation commands for parametric models	285
14.1	Use of predict after streg	285
14.1.1	Predicting the time of failure	287
14.1.2	Predicting the hazard and related functions	293
14.1.3	Calculating residuals	296
14.2	Using stcurve	298
14.3	Predictive margins and marginal effects	302
14.3.1	Predictive margins	302
Marginal mean survival time	302	
Marginal survival probabilities	307	
Multiple-record data	309	
14.3.2	Marginal effects	311
15	Generalizing the parametric regression model	317
15.0.3	Using the ancillary() option	317
15.0.4	Stratified models	323
15.1	Frailty models	326
15.1.1	Unshared-frailty models	327
15.1.2	Example: Kidney data	328
15.1.3	Testing for heterogeneity	333
15.1.4	Shared-frailty models	341
16	Power and sample-size determination for survival analysis	349
16.1	Estimating sample size	352
16.1.1	Multiple-myeloma data	352
16.1.2	Comparing two survivor functions nonparametrically	354
16.1.3	Comparing two exponential survivor functions	358
16.1.4	Cox regression models	362
16.2	Accounting for withdrawal and accrual of subjects	365

16.2.1	The effect of withdrawal or loss to follow-up	365
16.2.2	The effect of accrual	366
16.2.3	Examples	369
16.3	Estimating power and effect size	376
16.4	Tabulating or graphing results	377
17	Competing risks	381
17.1	Cause-specific hazards	382
17.2	Cumulative incidence functions	383
17.3	Nonparametric analysis	384
17.3.1	Breast cancer data	385
17.3.2	Cause-specific hazards	386
17.3.3	Cumulative incidence functions	389
17.4	Semiparametric analysis	392
17.4.1	Cause-specific hazards	392
Simultaneous regressions for cause-specific hazards	395	
17.4.2	Cumulative incidence functions	399
Using stcrreg	399	
Using stcox	406	
17.5	Parametric analysis	407
References		409
Author index		417
Subject index		421