## Contents

T	wna	it Is K!	
	1.1	Introdu	ction to R
	1.2	Downlo	ading and Installing R
		1.2.1	Installing R under Windows
		1.2.2	Launching R
		1.2.3	A First Look at R (Interactive mode)
	1.3	Vectors	
		1.3.1	Naming Cautions
		1.3.2	Vector Indexing
		1.3.3	Generating Vector Sequences and Repeating Vector Constants
		1.3.4	Filtering Vectors
	1.4	Mode a	nd Class of an Object
	1.5		Help
	1.6	_	d Editors
	1.7	RStudio	
	1.8	Package	28
	1.9	_	Structures
	-	1.9.1	Arrays and Matrices
		1.9.2	Vector and Matrix Operations
		1.9.3	Factors
		1.9.4	Lists
		1.9.5	Data Frames
		1.0.0	1.9.5.1 Creating Data Frames
			1.9.5.2 Accessing Data Frames
			1.9.5.3 Accessing Data from Packages
	1.10	Reading	g and Saving Data in R
	1.10	1.10.1	Using read.table()
		1.10.2	Using download.file()
		1.10.3	Reading Data from Secure Web Sites
		1.10.4	Using scan()
		1.10.5	Reading Excel (.xlsx) Files
		1.10.6	Saving Data Frames to External Files
	1.11		g with Data
	1.11	1.11.1	Dealing with NA Values
		1.11.2	Creating New Variables in a Data Frame
		1.11.3	Sorting a Data Frame by One or More of Its Columns
		1.11.4	Merging Data Frames
	1.12		ogical Operators with Data Frames
	1.12	Tables	
	1.13		rizing Functions
	1.14 $1.15$		ility Functions
	1.15		entrol
	1 111	1' 1C 1W/ 1 /	Julia Cu

	1.17		g Functions
	1.18	Simple	Imputation
	1.19	Using p	plot() 79
	1.20	Coordi	nate Systems and Traditional Graphic's States
	1.21	Probler	ns 90
<b>2</b>	Expl	oring D	Pata 97
_	2.1		s Statistics?
	2.2		
	2.3		ing Qualitative Data
		2.3.1	Tables
		2.3.2	Barplots
		2.3.3	Dot Charts
		2.3.4	Pie Charts
	2.4		ing Quantitative Data
	2.4	2.4.1	Stem-and-Leaf Plots
		2.4.1 $2.4.2$	Strip Charts
		2.4.3	Density Curves for Exploring Univariate Data
		2.4.0	2.4.3.1 Histograms
			2.4.3.2 Kernel Density Estimators
	2.5	Summe	ry Measures of Location
	2.0	2.5.1	The Mean
		2.5.1 $2.5.2$	The Median
		2.5.2 $2.5.3$	Mode
		2.5.3 $2.5.4$	Quantiles
		2.5.4 $2.5.5$	Hinges and the Five-Number Summary
		2.5.6	Boxplots
	2.6		ry Measures of Spread
	2.0	2.6.1	•
		2.6.1 $2.6.2$	Range
		2.6.2 $2.6.3$	
		2.6.3 $2.6.4$	
			-
	2.7	2.6.5	
	2.1	2.7.1	te Data
		2.7.1 $2.7.2$	Graphical Representations of Two-Way Contingency Tables 136
		2.7.2 $2.7.3$	
			1 0 1
		2.7.4	1
		2.7.5	Correlation
		2.7.6	Sorting a Data Frame by One or More of Its Columns
	0.0	2.7.7	Fitting Lines to Bivariate Data
	2.8	-	ex Plot Arrangements
	2.9		riate Data
		2.9.1	Graphs for Categorical Data
		2.9.2	Lattice Graphs
		2.9.3	Arranging Several Lattice Graphs on a Single Page 166
		2.9.4	Panel Functions
		2.9.5	Graphics with ggplot2
			2.9.5.1 Shading a Region of a Density Curve
			2.9.5.2 Violin Plots
			2.9.5.3 Adding a Smoothed Line

293

4.3.6

4.3.7

	4.4	Probler	ms		308
5	Mult	tivariate	e <b>Probab</b> i	ility Distributions	317
	5.1	Joint D	Distribution	n of Two Random Variables	317
		5.1.1	Joint pdf	for Two Discrete Random Variables	317
		5.1.2	Joint pdf	for Two Continuous Random Variables	319
	5.2	Indepe	ndent Ran	dom Variables	320
	5.3	Several	Random '	Variables	321
	5.4			ibutions	324
	5.5			Covariance, and Correlation	328
		5.5.1	,	Values	328
		5.5.2		ce	330
		5.5.3		on	333
	5.6	0.0.0	omial Dist		334
	5.7			Distribution	336
	5.8	Problei	iis		344
6	Sam		_	ing Distributions	353
	6.1	Sampli	0		353
		6.1.1	-	andom Sampling	354
		6.1.2	Stratified	Sampling	356
		6.1.3	Systemat	ic Sampling	357
		6.1.4	Cluster S	Sampling	357
	6.2	Parame	eters		358
		6.2.1	Infinite P	Populations' Parameters	358
		6.2.2	Finite Po	pulations' Parameters	359
	6.3	Estima	tors		359
		6.3.1	Plug-In F	Principle	361
	6.4	Sampli	_	ution of the Sample Mean	361
	6.5	-	_	ition for a Statistic from an Infinite Population	369
		6.5.1	_	Distribution for the Sample Mean	369
		0.0.	6.5.1.1	First Case: Sampling Distribution of $\bar{X}$ when Sampling	
			0.0.1.1	from a Normal Distribution	370
			6.5.1.2	Second Case: Sampling Distribution of $\bar{X}$ when $X$ Is not	
			0.0	a Normal Random Variable	372
		6.5.2	Sampling	Distribution for $\bar{X} - \bar{Y}$ when Sampling from Two Inde-	٠. ـ
		0.0.		Normal Populations	377
		6.5.3		Distribution for the Sample Proportion	379
		6.5.4		Value and Variance of the Uncorrected Sample Variance	0.0
		0.0.1		Sample Variance	383
	6.6	Sampli		ations Associated with the Normal Distribution	385
	0.0	6.6.1		are Distribution $(\chi^2)$	385
		0.0.1	6.6.1.1	The Relationship between the $\chi^2$ Distribution and the	300
			0.0.1.1	Normal Distribution	200
			6619	Sampling Distribution for $S_u^2$ and $S^2$ when Sampling	388
			6.6.1.2	**	390
		669	+ Diatmil	from Normal Populations	
		6.6.2	t-Distribu		396
	c 7	6.6.3		istribution	399
	6.7	Problei	ms		402

7	Poin	t Estin	nation	409
	7.1	Introdu	uction	409
	7.2	Proper	rties of Point Estimators	409
		7.2.1	Mean Square Error	409
		7.2.2	Unbiased Estimators	410
		7.2.3	Efficiency	413
			7.2.3.1 Relative Efficiency	414
		7.2.4	Consistent Estimators	417
		7.2.5	Robust Estimators	419
	7.3	Point I	Estimation Techniques	420
	-	7.3.1	Method of Moments Estimators	421
		7.3.2	Likelihood and Maximum Likelihood Estimators	423
			7.3.2.1 Fisher Information	435
			7.3.2.2 Fisher Information for Several Parameters	437
			7.3.2.3 Properties of Maximum Likelihood Estimators	439
			7.3.2.4 Finding Maximum Likelihood Estimators for Multiple	100
			Parameters	444
			7.3.2.5 Multi-Parameter Properties of MLEs	447
	7.4	Proble		448
8	Conf		Intervals	457
	8.1		uction	457
	8.2		ence Intervals for Population Means	458
		8.2.1	Confidence Interval for the Population Mean when Sampling from	
			a Normal Distribution with Known Population Variance	458
			8.2.1.1 Determining Required Sample Size	464
		8.2.2	Confidence Interval for the Population Mean when Sampling from	
			a Normal Distribution with Unknown Population Variance	468
		8.2.3	Confidence Interval for the Difference in Population Means when	
			Sampling from Independent Normal Distributions with Known	
			Equal Variances	470
		8.2.4	Confidence Interval for the Difference in Population Means when	
			Sampling from Independent Normal Distributions with Known but	
			Unequal Variances	474
		8.2.5	Confidence Interval for the Difference in Means when Sampling	
			from Independent Normal Distributions with Variances That Are	450
		0.0.0	Unknown but Assumed Equal	478
		8.2.6	Confidence Interval for a Difference in Means when Sampling from	
			Independent Normal Distributions with Variances That Are Un-	400
		0.0.7	known and Unequal	480
		8.2.7	Confidence Interval for the Mean Difference when the Differences	101
	0.9	Confid	Have a Normal Distribution	484
	8.3	8.3.1	ence Intervals for Population Variances	488
		8.3.1	Confidence Interval for the Population Variance of a Normal Population	100
		099	ulation	488
		8.3.2	Sampling from Independent Normal Distributions	492
	8.4	Confid	ence Intervals Based on Large Samples	$\frac{492}{495}$
	0.4	8.4.1	Confidence Interval for the Population Proportion	496
		0.4.1	8.4.1.1 Score Confidence Interval	501
			0.4.1.1 DOUG COMMUNICE INTERVAL	OOT

			8.4.1.2 Agresti-Coull Confidence Interval for the Population Proportion	502
			8.4.1.3 The Clopper-Pearson Interval for the Population Pro-	702
				503
			•	503
		8.4.2		511
		8.4.3		513
	8.5	Problei		515
9	Hyp	othesis	Testing 5	23
	9.1	Introdu	iction	523
	9.2	Type I	and Type II Errors	524
	9.3	Power :	Function	528
	9.4		· ·	531
	9.5			533
	9.6		<u>e</u>	534
	9.7			536
		9.7.1	Test for the Population Mean when Sampling from a Normal Dis-	
				536
		9.7.2	Test for the Population Mean when Sampling from a Normal Dis-	
			*	38
		9.7.3	Test for the Difference in Population Means when Sampling from	
		0.7.4	•	646
		9.7.4	Test for the Difference in Means when Sampling from Independent	
			Normal Distributions with Variances That Are Unknown but As-	: 10
		0.7 5	sumed Equal	548
		9.7.5	Normal Distributions with Variances That Are Unknown and not	
				552
		9.7.6	Test for the Mean Difference when the Differences Have a Normal	102
		5.1.0		555
	9.8	Hypoth		559
	0.0	9.8.1	Test for the Population Variance when Sampling from a Normal	
				559
		9.8.2	Test for Equality of Variances when Sampling from Independent	
			Normal Distributions	662
	9.9	Hypoth	nesis Tests for Population Proportions	666
		9.9.1	Testing the Proportion of Successes in a Binomial Experiment (Ex-	
			, , , , , , , , , , , , , , , , , , ,	666
		9.9.2	Testing the Proportion of Successes in a Binomial Experiment (Nor-	
			7	669
		9.9.3	0 1 V 1	573
		9.9.4	Large Sample Approximation for Testing the Difference of Two	
				579
	9.10	Problei	$\operatorname{ms}$ 5	83
10	Non	narama	tric Methods 5	91
τU	10.1	_		<b>9</b> 1 591
	10.1 $10.2$	Sign Te		592
	10.2	10.2.1		592 592
		-		593

	10.3	Wilcoxon Signed-Rank Test	598
		10.3.1 Confidence Interval for $\psi$ Based on the Wilcoxon Signed-Rank Test 6	603
		10.3.2 Normal Approximation to the Wilcoxon Signed-Rank Test 6	607
	10.4	The Wilcoxon Rank-Sum or the Mann-Whitney $U$ -Test $\ldots$	612
		10.4.1 Confidence Interval Based on the Mann-Whitney $U$ -Test 6	316
		10.4.2 Normal Approximation to the Wilcoxon Rank-Sum and Mann-	
		Whitney $U$ -Tests	319
	10.5	The Kruskal-Wallis Test	626
	10.6	Friedman Test for Randomized Block Designs	333
	10.7	Goodness-of-Fit Tests	638
		10.7.1 The Chi-Square Goodness-of-Fit Test	639
		10.7.2 Kolmogorov-Smirnov Goodness-of-Fit Test	645
		10.7.3 Shapiro-Wilk Normality Test	352
	10.8	Categorical Data Analysis	653
		10.8.1 Test of Independence	355
		10.8.2 Test of Homogeneity	658
	10.9	Nonparametric Bootstrapping	660
		10.9.1 Bootstrap Paradigm	660
		10.9.2 Confidence Intervals	670
		10.9.3 Bootstrapping and Regression	680
	10.10	Permutation Tests	685
	10.11	Problems	392
	-		
11	-	8	'01
	11.1		701
	11.2		706
	11.3	v /	707
	11.4		713
	11.5		722
		9 1	723
		Ÿ	724
	11.0	9	726
	11.6		728
		v	729
	11 7		730
	11.7	1 1	734
		9	734
		v v c	736
	11.0	1 0 0	737
	11.8		737
		· · · · · · · · · · · · · · · · · · ·	738
	11.0		744 744
	11.9	v i	744 740
		,	749
			752 764
		<u> </u>	764
	11.13	Problems	775

<b>12</b>	Regr	ression 78	<b>85</b>
	12.1	Introduction	85
	12.2	Simple Linear Regression	87
	12.3	Multiple Linear Regression	88
	12.4	Ordinary Least Squares	89
	12.5		92
	12.6	Using Matrix Notation with Ordinary Least Squares	93
	12.7	The Method of Maximum Likelihood	00
	12.8	The Sampling Distribution of $\hat{\beta}$	01
	12.9		04
			05
		12.9.2 ANOVA with Multiple Linear Regression	09
			10
			11
			16
			19
	12.10	· · · · · · · · · · · · · · · · · · ·	20
			26
			26
		~	26
			26
			26
			33
			38
		· ·	38
			38
			40
			40
			42
			48
		· ·	54
			57
		12.11.3.2 Transformations for Non-Normality and Unequal Error	
			60
	12.12		66
			67
			68
			69
	12.13		75
			77
		·	83
			84
			87
		12.17.1 Simultaneous Confidence Intervals for Several Mean Responses —	
			88
			88
		12.17.3 Distinguishing Pointwise Confidence Envelopes from Confidence	. •
			88
	12.18		95
$\mathbf{A}$	R Co	ommands 90	07

			xix				
		Table 1011116 and 101114011 (000015 and 1)24011605	921				
	B.1 B.2	Quadratic Forms					
	B.3	Variance of Random Vectors	922				
References							
Inc	index 9						