## Contents

Seri	es Ec	litor's Introduction	xi
Pref	face		xvii
1.	Pro	logue: Regression Analysis as Problematic	1
2.	A G	rounded Introduction to Regression Analysis	5
	2.1	Some Examples of Regression Analysis	5
		2.1.1 Abortion and Subsequent Crime	5
		2.1.2 Mandatory Basic Education	
		for Welfare Recipients	6
		2.1.3 Gender and Academic Salaries	7
		2.1.4 Climate Change and Water Resources in India	8
		2.1.5 Deforestation and Soil Erosion in the Yangtze	
		River Valley	8
		2.1.6 Epidemics of Hepatitis C	9
		2.1.7 Onward and Upward	9
	2.2	What Is Regression Analysis?	10
		2.2.1 A Simple Illustration	10
		2.2.2 Controlling for a Third Variable	13
		2.2.3 Imposing a Smoother	16
	2.3	Getting From Data to Stories	18
3.	Sim	Simple Linear Regression	
	3.1	Introduction	21
	3.2	Describing a Conditional Relationship	
		With a Straight Line	22
	3.3	Defining the "Best" Line	24
	3.4	Some Useful Formulas	27
	3.5	Standardized Slopes	28
	3.6	Using Transformations for a Nonlinear Fit	30
	3.7	What About the Variance Function?	35
	3.8	Summary and Conclusions	37
4.	Statistical Inference for Simple Linear Regression		
	4.1	The Role of Sampling	39
		4.1.1 Random Sampling	39
		4.1.2 Strategy I: Treating the Data as Population	42

		4.1.3	Strategy II: Treating the Data as If They Were	
			Generated by Random Sampling From a Population	44
		4.1.4	Strategy III: Inventing an Imaginary Population	51
		4.1.5	Strategy IV: Model-Based Sampling-Inventing	
			a Friendly Natural Process Responsible for the Data	53
		4.1.6	A Note on Randomization Inference	56
		4.1.7	Summing Up	58
	4.2	Simpl	e Linear Regression Under Random Sampling	58
		4.2.1	Estimating the Population Regression Line	58
		4.2.2	Estimating the Standard Errors	61
		4.2.3	Estimation Under Model-Based Sampling	62
		4.2.4	Some Things That Can Go Wrong	62
		4.2.5	Tests and Confidence Intervals	65
	4.3	Statist	ical Power	69
	4.4	Stoch	astic Predictors	69
	4.5	Measu	arement Error	73
	4.6	Can R	esampling Techniques Help?	74
		4.6.1	Percentile Confidence Intervals	76
		4.6.2	Hypothesis Testing	77
		4.6.3	Bootstrapping Regression	77
		4.6.4	Possible Benefits From Resampling	78
	4.7	Summ	ary and Conclusions	79
5.	Cau	sal Inf	erence for the Simple Linear Model	81
	5.1	Introd	uction	81
		muou		
	5.2	Some	Definitions: What's a Causal Effect?	82
	5.2	Some 5.2.1	Definitions: What's a Causal Effect? The Neyman-Rubin Model	82 84
	5.2	Some 5.2.1 5.2.2	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects	82 84
	5.2	Some 5.2.1 5.2.2	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules	82 84 88
	5.2	Some 5.2.1 5.2.2 5.2.3	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention?	82 84 88 90
	5.2 5.3	Some 5.2.1 5.2.2 5.2.3 Study	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data	82 84 88 90 97
	5.2 5.3	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions	82 84 88 90 97
	5.2 5.3	5.2.1 5.2.2 5.2.3 5.2.3 5.2.3	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences	82 84 88 90 97 97
	5.2	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1 5.3.2	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences Using Statistical Solutions for Making	82 84 88 90 97 97
	5.2	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1 5.3.2	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences Using Statistical Solutions for Making Causal Inferences	82 84 88 90 97 97 97
	5.2	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1 5.3.2 5.3.3	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences Using Statistical Solutions for Making Causal Inferences Using the Simple Linear Model	82 84 88 90 97 97 97 98
	5.2	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1 5.3.2 5.3.3	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences Using Statistical Solutions for Making Causal Inferences Using the Simple Linear Model for Making Causal Inferences	82 84 88 90 97 97 97 98 99
	5.2 5.3 5.4	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1 5.3.2 5.3.3 Sumn	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences Using Statistical Solutions for Making Causal Inferences Using the Simple Linear Model for Making Causal Inferences hary and Conclusions	82 84 90 97 97 97 98 99 101
6.	5.2 5.3 5.4 The	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1 5.3.2 5.3.3 Sumn Forma	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences Using Statistical Solutions for Making Causal Inferences Using the Simple Linear Model for Making Causal Inferences hary and Conclusions alities of Multiple Regression	82 84 88 90 97 97 97 98 99 101 <b>103</b>
6.	5.2 5.3 5.4 The 6.1	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1 5.3.2 5.3.3 Summ Forma	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences Using Statistical Solutions for Making Causal Inferences Using the Simple Linear Model for Making Causal Inferences hary and Conclusions alities of Multiple Regression luction	82 84 88 90 97 97 97 98 99 101 <b>103</b> 103
6.	5.2 5.3 5.4 The 6.1 6.2	Some 5.2.1 5.2.2 5.2.3 Study 5.3.1 5.3.2 5.3.3 Sumn Forma Introc Terms	Definitions: What's a Causal Effect? The Neyman-Rubin Model Thinking About Causal Effects as Response Schedules What's an Intervention? ing Cause and Effect With Data Using Nonstatistical Solutions for Making Causal Inferences Using Statistical Solutions for Making Causal Inferences Using the Simple Linear Model for Making Causal Inferences hary and Conclusions alities of Multiple Regression luction s and Predictors	82 84 88 90 97 97 98 99 101 <b>103</b> 103 103

	6.4	Estimation	105		
	6.5	How Multiple Regression "Holds Constant"	107		
	6.6	Summary and Conclusions	110		
7.	Usir	sing and Interpreting Multiple Regression			
	7.1	Introduction	111		
	7.2	Another Formal Perspective on Holding Constant	111		
	7.3	When Does Holding Constant Make Sense?	113		
	7.4	Standardized Regression Coefficients:			
		Once More With Feeling	117		
	7.5	Variances of the Coefficient Estimates	119		
	7.6	Summary and Conclusions	122		
8.	Son	e Popular Extensions of Multiple Regression	125		
	8.1	Introduction	125		
	8.2	Model Selection and Stepwise Regression	126		
		8.2.1 Model Selection by Removing Terms	127		
		8.2.2 Tests to Compare Models	128		
		8.2.3 Selecting Terms Without Testing	130		
		8.2.4 Stepwise Selection Methods	132		
		8.2.5 Some Implications	133		
	8.3	Using Categorical Terms: Analysis of Variance			
		and Analysis of Covariance	135		
		8.3.1 An Extended Example	135		
	8.4	Back to the Variance Function:			
		Weighted Least Squares	141		
		8.4.1 Visualizing Lack of Fit	141		
		8.4.2 Weighted Least Squares as a Possible Fix	142		
		8.4.3 Evaluating the Mean Function	145		
	8.5	Locally Weighted Regression Smoother	147		
	8.6	Summary and Conclusions	148		
9.	Som	ne Regression Diagnostics	151		
	9.1	Introduction	151		
	9.2	Transformations of the Response Variable	152		
		9.2.1 Box-Cox Procedures	152		
		9.2.2 Inverse Fitted Value Response Plots	153		
	9.3	Leverage and Influence	159		
		9.3.1 Influential Cases and Cook's Distance	159		
	9.4	Cross-Validation			
	9.5	Misspecification Tests	163		
		9.5.1 Instrumental Variables	164		
		9.5.2 Tests for Exogeneity	167		
	9.6	Conclusions	168		

10.	Further E	xtensions of Regression Analysis	171
	10.1 Regr	ession Models for Longitudinal Data	171
	10.1.	Multiple Linear Regression for Time Series Data	172
	10.2 Regr	ession Analysis With Multiple	
	Time	Series Data	177
	10.2.	I Fixed Effects Models	178
	10.2.3	2 Random Effects Models	178
	10.2.	3 Estimation	180
	10.3 Mult	ilevel Models	180
	10.4 The	Generalized Linear Model	183
	10.4.	I GLM Structure	183
	10.4.	2 Normal Models	184
	10.4.	3 Poisson Models	184
	10.4.	4 Poisson Models for Contingency Tables	186
	10.4.	5 Binomial Regression	186
	10.5 Mult	iple Equation Models	188
	10.5.	1 Causal Inference Once Again	191
	10.5.	2 A Final Observation	196
	10.6 Meta	-Analysis	196
	10.7 Conc	lusions	200
11.	What to I	Do la	203
	11.1 How	Did We Get Into This Mess?	203
	11.2 Three	e Cheers for Description	206
	11.2.	1 What's Description?	207
	11.2.	2 Advocacy Settings	207
	11.2.	3 Descriptive Regressions as Part of a Broad	
		Research Program	209
	11.2.	4 Spotting Provocative Associations	210
	11.2.	5 Some Other Benefits of Description	212
	11.3 Two	Cheers for Statistical Inference	218
	11.3.	1 Working With Near-Random Samples	220
	11.3.	2 Working With Data From Nature	222
	11.3.	3 Working With a Nearly Correct Model	222
	11.4 One	Cheer for Causal Inference	223
	11.4.	1 Special-Purpose Estimators	226
	11.4.	2 Propensity Scores	230
	11.4.	3 Sensitivity Analysis of the Selection Process	231
	11.4.	4 Bounding Treatment Effects	232
	11.4.	5 Some Forecasts	234
	11.5 Som	e Final Observations	234
	11.5.	1 A Police Story	234
	11.5.	2 Regression Analysis as Too Little, Too Late	237
Ref	erences		239
Ind	ex		251
About the Author			259