Contents

Prefe	ace	page xi
Prefe	ace to the second edition	xiii
Preli	minaries	1
1.1	The shadow's cause	1
1.2	Fisher's genius and the randomised experiment	5
1.3	The controlled experiment	11
1.4	Physical controls and observational controls	13
From	cause to correlation and back	17
2.1	Translating from causal to statistical models	17
2.2	Directed graphs	20
2.3	Causal conditioning	23
2.4	D-separation	23
2.5	Probability distributions	27
2.6	Probabilistic (conditional) independence	29
2.7	The Markov condition	31
2.8	The translation from causal models to observational models	32
2.9	Counter-intuitive consequences and limitations of d-separation:	
	conditioning on a causal child	33
2.10	Counter-intuitive consequences and limitations of d-separation:	
	conditioning due to selection bias	36
2.11	Counter-intuitive consequences and limitations of d-separation: feedback	
	loops and cyclic causal graphs	36
2.12	Counter-intuitive consequences and limitations of d-separation: imposed	
	conservation relationships	38
2.13	Counter-intuitive consequences and limitations of d-separation:	
	unfaithfulness	39
2.14	Counter-intuitive consequences and limitations of d-separation:	
	context-sensitive independence	41
	The logic of causal inference	42
2.16	Statistical control is not always the same as physical control	47
2.17	A taste of things to come	5.4

3	Sewal	Il Wright, path analysis and d-separation	56
	3.1	A bit of history	56
	3.2	Why Wright's method of path analysis was ignored	57
	3.3	D-sep tests	60
	3.4	Independence of d-separation statements	61
		Testing for probabilistic independence	63
	3.6	Permutation tests of independence	68
	3.7	Form-free regression	69
	3.8	Conditional independence	71
	3.9	Spearman partial correlations	74
	3.10	Seed production in St Lucie cherry	78
	3.11	Generalising the d-sep test	81
4	Path :	analysis and maximum likelihood	87
	4.1	Testing path models using maximum likelihood	89
	4.2	Decomposing effects in path diagrams	105
	4.3	Multiple regression expressed as a path model	109
	4.4	Maximum-likelihood estimation of the gas exchange model	111
	4.5	Using lavaan to fit path models	114
5	Meas	surement error and latent variables	126
	5.1	Measurement error and the inferential tests	127
	5.2	Measurement error and the estimation of path coefficients	130
	5.3	A measurement model	131
	5.4	Fitting a measurement model in lavaan	140
	5.5	The nature of latent variables	142
	5.6	Horn dimensions in bighorn sheep	146
	5.7	Body size in bighorn sheep	147
	5.8	The worldwide leaf economic spectrum	149
	5.9	Name calling	151
6	The	structural equation model	153
M	6.1	Parameter identification	154
	6.2	Structural under-identification with measurement models	155
	6.3	Structural under-identification with structural models	159
	6.4	Representing composite variables using latents	163
	6.5	Behaviour of the maximum-likelihood chi-square statistic with small	
		sample sizes	165
	6.6	Behaviour of the maximum-likelihood chi-square statistic with data that	
		do not follow a multivariate normal distribution	169
	6.7	Solutions for modelling non-normally distributed variables	175
	6.8	Alternative measures of 'approximate' fit	177
	6.9	Bentler's comparative fit index (CFI)	180
	6.10	Approximate fit measured by the root mean square error of approximation	
		(RMSEA)	182

6.1	1 Missing data	183
6.1	2 Reporting results in publications	184
6.1	3 An SEM analysis of the Bumpus house sparrow data	185
Mu	ltigroup models, multilevel models and corrections for the non-independence	
of o	observations	188
7.1	1100000	189
7.2	B models	190
7.3	The dangers of hierarchically structured data	200
7.4	Multilevel SEM	210
Exp	loration, discovery and equivalence	221
8.1	Hypothesis generation	221
8.2	Exploring hypothesis space	222
8.3	The shadow's cause revisited	224
8.4	Obtaining the undirected dependency graph	226
8.5	The undirected dependency graph algorithm	228
8.6	Interpreting the undirected dependency graph	231
8.7	Orienting edges in the undirected dependency graph using unshielded	
	colliders assuming an acyclic causal structure	234
8.8	The orientation algorithm using unshielded colliders	236
8.9	Orienting edges in the undirected dependency graph using definite	
	discriminating paths	239
8.10	The causal inference algorithm	241
8.11	Equivalent models	242
8.12	Detecting latent variables	243
8.13	Vanishing tetrad algorithm	247
	Separating the message from the noise	248
8.15	The causal inference algorithm and sampling error	252
8.16	The vanishing tetrad algorithm and sampling variation	257
8.17	Empirical examples	258
8.18	Orienting edges in the undirected dependency graph without assuming an	
9 10	acyclic causal structure	264
	The cyclic causal discovery algorithm In conclusion	268
0.20	in conclusion	272
Appe	endix: A cheat-sheet of useful R functions	273
	rences	290
		270

Index

Contents

iχ

297