## Steffen Christ

## **Operationalizing Dynamic Pricing Models**

Bayesian Demand Forecasting and Customer Choice Modeling for Low Cost Carriers

With a foreword by Prof. Dr. Robert Klein



RESEARCH

## Contents

Li	XV				
List of Tables					
Nomenclature					
M	athe	matical Nomenclature	X	xν	
Μ	athe	matical Notation X	X٧	VII	
Ι	Dy	ynamic Pricing in the Airline Industry		1	
1	Intr	roduction		3	
-	1 1	The Passenger Airline Industry		3	
	1 2	The Low Cost Revolution	•	6	
	1.2	The Advent of Dynamic Pricing	•	11	
2	Mo	tivation and Structure		15	
	2.1	Relevance of the Topic		15	
	2.2	Focus on the Airline Industry		18	
	2.3	Objective and Differentiation		19	
	2.4	Structure of Work	•	20	
3	Dyı	namic Pricing		23	
	3.1	Definition and Scope	•	23	
		3.1.1 Introduction to Pricing	•	23	
		3.1.2 Dynamic Pricing and Revenue Optimization	·	25	
	3.2	Literature Overview		31	
		3.2.1 Demand Learning Models		31	
		3.2.2 Non-learning Pricing Models		42	
		3.2.2.1 Dynamic Pricing with Myopic Customers		45	

1

		3.2.2.2 Dynamic Pricing with Strategic Customers	51
		3.2.2.3 Customer Choice Models	53
	3.3	Limitations and Shortcomings	54
		3.3.1 Dynamic Pricing Models	54
		3.3.2 Demand Learning Models	56
	3.4	Proposed Approach	58
Π	Fo	precasting Latent Demand	63
Pa	rt II	Objective	65
4	Self	Learning Linear Models	67
	4.1	Linear Regression Models	68
	4.2	Bayesian Statistics	79
		4.2.1 Bayesian Probabilities	80
		4.2.2 Bayesian Inference	83
	4.3	Bayesian Linear Regression	85
		4.3.1 Parameter Distribution	85
		4.3.2 Predictive Distribution	89
	4.4	Critique and Limitations	92
<b>5</b>	Den	nand in Low Cost Markets	97
	5.1	Experimental Data Set	97
		5.1.1 Data Collection	98
		5.1.2 Data Cleansing	101
	5.2	Overarching Long-term Characteristics	103
		5.2.1 Log-linear Demand Structure	104
		5.2.2 Macro-Seasonalities and Trends	110
		5.2.3 Similarities of Adjacent Flights	113
	5.3	Short-term Characteristics	115
		5.3.1 Time Series Disruption Through Outliers	116
		5.3.2 Patterns Based on Departure Weekdays	121
		5.3.3 Micro-Seasonalities along Observation Weekdays	125
		5.3.4 Cross-Effects of Departure and Observation Weekdays	128
	5.4	Implications for Forecasting Model	129
6	$\mathbf{The}$	Demand Forecasting Model	131
	6.1	Linear Basis Function Model	131
		6.1.1 Indexing and Data Transformation	132
		6.1.2 Driving Model Parameters	134

		6.1.3	Model Specification and Re-transformation	138
		6.1.4	Frequentist Coefficient Weights	140
	6.2	Model	Validation	141
		6.2.1	Model and Coefficient Significance	142
		6.2.2	Prerequisites and Assumptions	144
	6.3	Bayesi	an Learning Mechanism	146
		6.3.1	Online Demand Learning	147
		6.3.2	Overarching Demand Structures and Prior	
			Demand Knowledge	153
7	Con	nniitat	ional Results and Evaluation	159
•	71	Perfor	mance of the Naïve Bayesian Scheme	159
		711	Distribution Convergence Speed	159
		7.1.1	Forecast Quality and Accuracy	164
	72	Sensiti	vity of Forecast Accuracy	168
	1.2	721	Improvement Through Informed Priors	169
		722	Sizing of Learning window	172
		7.2.3	Granularity of Forecasting Basis	. 178
		7.2.4	Combined Effects	181
	7.3	Record	mended Approach	185
8	Sun	nmary	and Outlook	189
8	Sun	nmary	and Outlook	189
8 11	Sun I I	nmary Estim	and Outlook ating Price Sensitivity	189 199
8 II Pa	Sun I I art II	nmary Estim II Obje	and Outlook ating Price Sensitivity ective	189 199 201
8 II Pa 9	Sun I I art II Disc	nmary Estim II Obje crete C	and Outlook ating Price Sensitivity ective Customer Choice Analysis	189 199 201 203
8 II Pa 9	Sun I I art II Dise 9.1	nmary Estim II Obje crete C Funda	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 204
8 II Pa 9	Sun I I art II 0.1 9.2	nmary Estim II Obje crete C Funda Eleme	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 204 206
8 II Pa 9	Sun I I art II Disc 9.1 9.2	nmary Estim II Obje crete C Funda Eleme 9.2.1	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 . 204 . 206 . 207
8 11 9	Sun III art II Disc 9.1 9.2	nmary Estim II Obje Crete C Funda Eleme 9.2.1 9.2.2	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling Decision Maker and its Characteristics Choice Set	189 199 201 203 204 204 206 207 207 208
8 II Pa 9	Sun III art II Disc 9.1 9.2	nmary Estim II Obje crete C Funda Eleme 9.2.1 9.2.2 9.2.3	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 204 206 207 206 207 208 208 209
8 II P: 9	Sun III art II Dise 9.1 9.2	<b>Estim</b> <b>II Obje</b> <b>crete C</b> Funda Eleme 9.2.1 9.2.2 9.2.3 9.2.4	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling nts of a Choice Decision Process Decision Maker and its Characteristics Choice Set Alternative Attributes Decision.Rule	189 199 201 203 203 203 203 204 207 207 208 207 208 209 209 209 209
8 11 P: 9	Sum I ] art I] 9.1 9.2 9.3	nmary Estim II Obje Crete C Funda Eleme 9.2.1 9.2.2 9.2.3 9.2.4 Indivio	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 203 203 203 204 207 207 208 209 209 209 210 211
8 11 Pa 9	Sun I I art II 9.1 9.2 9.3	<b>Estim</b> <b>II Obje</b> <b>Crete C</b> Funda Eleme 9.2.1 9.2.2 9.2.3 9.2.4 Indivia 9.3.1	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 . 204 . 206 . 207 . 208 . 209 . 210 . 211 . 211
8 11 P: 9	Sun III art II 9.1 9.2 9.3	Estim II Obje Crete C Funda Eleme 9.2.1 9.2.2 9.2.3 9.2.4 Indivia 9.3.1 9.3.2	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 204 203 204 203 204 207 208 207 208 209 210 210 211 211 213
8 11 Pa 9	Sun I I art II 9.1 9.2 9.3	<b>Estim</b> <b>II Obje</b> <b>Crete C</b> Funda Eleme 9.2.1 9.2.2 9.2.3 9.2.4 Indivia 9.3.1 9.3.2 9.3.3	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 203 203 204 206 207 207 208 209 209 210 211 211 213 213 215
8 11 9	Sum III art II 9.1 9.2 9.3 9.3	<b>Estim</b> <b>II Obje</b> <b>Crete C</b> Funda Eleme 9.2.1 9.2.2 9.2.3 9.2.4 Indivio 9.3.1 9.3.2 9.3.3 The M	and Outlook ating Price Sensitivity ective Customer Choice Analysis mentals of Choice Modeling	189 199 201 203 203 203 204 204 207 207 207 207 207 207 207 207

## CONTENTS

		9.4.2	Specific Properties and Limitations	. 220		
		9.4.3	Coefficient Estimation	. 224		
		9.4.4	Tests of Model Specifications	. 226		
10 Choice Situation in Low-Cost Markets						
	10.1	Experi	mental Data Set	. 233		
	10.2	Marke	t Overview	. 238		
		10.2.1	Market Participants and Supply	. 238		
		10.2.2	Pricing Environment and Behavior	. 239		
	10.3	Observ	ved Demand Behavior	. 243		
		10.3.1	Price Sensitivity	. 243		
		10.3.2	Schedule Preference	. 247		
		10.3.3	Booking Day Preference	. 249		
	10.4	Implic	ations for Choice Model	. 250		
11	Mul	tinomi	ial Logit Model for Low-Cost Travel Choice	253		
	11.1	Modeli	ing Constraints and Specifics	. 255		
	11.2	Model	Building and Goodness of Fit	. 261		
		11.2.1	Internal Choice Drivers	. 262		
		11.2.2	Decision Maker Characteristics	. 268		
		11.2.3	External Outbound Choice Drivers	. 278		
		11.2.4	External Inbound Choice Drivers	. 294		
12	Con	iputati	ional Results and Evaluation	303		
	12.1	Predic	tive Model Performance	. 303		
	12.2	Choice	Elasticities of Fare Changes	. 311		
r	12.3	Applic	ations to Dynamic Airfare Pricing	. 316		
13	Sum	mary	and Outlook	319		
Aŗ	opene	dix		329		
Bi	Bibliography					