

GALIT SHMUELI

PRACTICAL  
TIME SERIES  
FORECASTING

A HANDS-ON GUIDE

THIRD EDITION

AXELROD SCHNALL PUBLISHERS

Copyright © 2016 Galit Shmueli and Statistics.com LLC

ISBN-13: 978-0-9915766-5-4

ISBN-10: 0-991-57665-9

Cover art: Lakhang in Eastern Bhutan, copyright © 2016 Galit Shmueli

ALL RIGHTS RESERVED. No part of this work may be used or reproduced, transmitted, stored or used in any form or by any means graphic, electronic, or mechanical, including but not limited to photocopying, recording, scanning, digitizing, taping, Web distribution, information networks or information storage and retrieval systems, or in any manner whatsoever without prior written permission.

For further information see [www.forecastingbook.com](http://www.forecastingbook.com)

*Third Edition, July 2016*

# Contents

<b>Preface</b>	<b>9</b>
<b>1 Approaching Forecasting</b>	<b>15</b>
1.1 Forecasting: Where? . . . . .	15
1.2 Basic Notation . . . . .	15
1.3 The Forecasting Process . . . . .	16
1.4 Goal Definition . . . . .	18
1.5 Problems . . . . .	23
<b>2 Time Series Data</b>	<b>25</b>
2.1 Data Collection . . . . .	25
2.2 Time Series Components . . . . .	28
2.3 Visualizing Time Series . . . . .	30
2.4 Interactive Visualization . . . . .	34
2.5 Data Pre-Processing . . . . .	38
2.6 Problems . . . . .	41
<b>3 Performance Evaluation</b>	<b>45</b>
3.1 Data Partitioning . . . . .	45
3.2 Naive Forecasts . . . . .	51
3.3 Measuring Predictive Accuracy . . . . .	52
3.4 Evaluating Forecast Uncertainty . . . . .	57
3.5 Problems . . . . .	59
<b>4 Forecasting Methods: Overview</b>	<b>61</b>
4.1 Model-Based vs. Data-Driven Methods . . . . .	61
4.2 Extrapolation Methods, Econometric Models, and Ex- ternal Information . . . . .	62

4.3	Manual vs. Automated Forecasting . . . . .	64
4.4	Combining Methods and Ensembles . . . . .	65
4.5	Problems . . . . .	69
<b>5</b>	<b>Smoothing Methods</b>	<b>71</b>
5.1	Introduction . . . . .	71
5.2	Moving Average . . . . .	72
5.3	Differencing . . . . .	77
5.4	Simple Exponential Smoothing . . . . .	79
5.5	Advanced Exponential Smoothing . . . . .	83
5.6	Extensions of Exponential Smoothing . . . . .	86
5.7	Problems . . . . .	90
<b>6</b>	<b>Regression Models: Trend &amp; Seasonality</b>	<b>101</b>
6.1	Model with Trend . . . . .	101
6.2	Model with Seasonality . . . . .	109
6.3	Model with Trend and Seasonality . . . . .	112
6.4	Creating Forecasts from the Chosen Model . . . . .	114
6.5	Problems . . . . .	117
<b>7</b>	<b>Regression Models: Autocorrelation &amp; External Info</b>	<b>127</b>
7.1	Autocorrelation . . . . .	127
7.2	Improving Forecasts by Capturing Autocorrelation: AR and ARIMA Models . . . . .	131
7.3	Evaluating Predictability . . . . .	137
7.4	Including External Information . . . . .	139
7.5	Problems . . . . .	145
<b>8</b>	<b>Forecasting Binary Outcomes</b>	<b>155</b>
8.1	Binary Outcomes . . . . .	155
8.2	Naive Forecasts and Performance Evaluation . . . . .	156
8.3	Logistic Regression . . . . .	157
8.4	Example: Rainfall in Melbourne, Australia . . . . .	159
8.5	Problems . . . . .	163
<b>9</b>	<b>Neural Networks</b>	<b>165</b>
9.1	Neural Networks for Forecasting Time Series . . . . .	165
9.2	The Neural Network Model . . . . .	166
9.3	Pre-Processing . . . . .	170

9.4	User Input . . . . .	171
9.5	Example: Forecasting Amtrak Ridership . . . . .	172
9.6	Problems . . . . .	177
<b>10</b>	<b>Communication and Maintenance</b>	<b>179</b>
10.1	Presenting Forecasts . . . . .	179
10.2	Monitoring Forecasts . . . . .	181
10.3	Written Reports . . . . .	182
10.4	Keeping Records of Forecasts . . . . .	183
10.5	Addressing Managerial "Forecast Adjustment" . . .	184
<b>11</b>	<b>Cases</b>	<b>187</b>
11.1	Forecasting Public Transportation Demand . . . . .	187
11.2	Forecasting Tourism (2010 Competition, Part I) . . .	191
11.3	Forecasting Stock Price Movements (2010 INFORMS Competition) . . . . .	195
	<b>Data Resources and Competitions</b>	<b>201</b>
	<b>Bibliography</b>	<b>203</b>
	<b>Index</b>	<b>207</b>