Financial Econometrics
Models and Methods

This is a thorough exploration of the models and methods of financial econometrics by one of the world's leading financial econometricians and is for students in economics, finance, statistics, mathematics, and engineering who are interested in financial applications.

Based on courses taught around the world, the up-to-date content covers developments in econometrics and finance over the past twenty years while ensuring a solid grounding in the fundamental principles of the field.

Care has been taken to link theory and application to provide real-world context for students, worked exercises and empirical examples have also been included to make sure complicated concepts are solidly explained and understood.

OLIVER LINTON is a fellow of Trinity College and is Professor of Political Economy at Cambridge University. Formerly, Professor of Econometrics at the London School of Economics and Professor of Economics at Yale University. He obtained his PhD in Economics from the University of California at Berkeley in 1991. He has written more than a hundred articles on econometrics, statistics, and empirical finance. In 2015 he was a recipient of the Humboldt Research Award of the Alexander von Humboldt Foundation. He has been a Co-editor at the Journal of Econometrics since 2014. He is a Fellow of: the Econometric Society, the Institute of Mathematical Statistics, the Society for Financial Econometrics, the British Academy, and the International Foundation of Applied Econometrics. He was a lead expert in the U.K. Government Office for Science Foresight project: "The future of Computer Trading in Financial Markets", which published in 2012. He has appeared as an expert witness for the FSA and the FCA in several cases involving market manipulation.

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OLIVER LINTON
University of Cambridge

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Shaftesbury Road, Cambridge CB2 8EA, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of Cambridge University Press & Assessment, a department of the University of Cambridge.

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www.cambridge.org
Information on this title: www.cambridge.org/9781107177154

DOI: 10.1017/9781316819302

First published 2019

A catalogue record for this publication is available from the British Library

ISBN 978-1-107-17715-4 Hardback
ISBN 978-1-316-63033-4 Paperback

Additional resources for this publication at www.cambridge.org/linton

Cambridge University Press & Assessment
978-1-107-17715-4 — Financial Econometrics
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To my wife, Jianghong Song.

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Preface

This work grew out of my teaching and research. It started from my considerable admiration of the seminal financial econometrics book Campbell, Lo, and MacKinlay (1997), henceforth CLM, and my teaching of that material to Master's students. I have kept along a similar line to that work in terms of selection of material and development, and have updated the material in several places. I have tried to adapt the material to a Master's audience by reducing the peerless literature review that is in that book and by amplifying some of the econometric discussions. I have included some theorems of varying degrees of rigor, meaning that I have not in every case specified all the required regularity conditions. I apologize for any upset this may cause, but the interests of time and space kept me from doing this. I hope the use of theorems can help to focus the material and make it easier to teach.

Financial econometrics has grown enormously as a discipline in the 20 years since CLM was published, and the range of authors engaged in its development has also increased. Computer scientists and so-called econo-physicists have taken an interest in the field and made major contributions to our understanding of financial markets. Mathematicians and statisticians have established rigorous proofs of many important results for our field and developed new tools for analyzing and understanding big financial data. The academic landscape has also become more international with a big expansion in the study of finance and financial statistics in China.

Data is the plural of anecdote, and happily there has recently been a massive increase in the amount of data, which has in itself stimulated research. Simultaneously computer power, both hardware and software, has increased substantially, allowing the analysis of much larger and more complex datasets than was previously possible. Econometric methodology has also expanded in many relevant areas, notably: volatility measurement and modelling; bounteous variate statistics where the size of the cross-section and time series is large; tools for extreme risk management; and quantifying causal effects. Despite the improvement in tools, the Global Financial Crisis following 2008, led to some skepticism about the value of economic theory and econometrics in predicting the armageddon that then ensued and in managing its aftermath, but this has in turn led to development of more relevant methodology, and hopefully some humility. Has all this attention and development improved our understanding of how financial markets work and how to change them for the better? I think so, but the subject is far from complete or satisfactory. The quantity and quality of empirical work and its presentation has improved substantially over time, but this has to some extent just made it harder for the reader to tell where the "bodies are buried" and what is the permanent value added of a particular study. Statistical methods are vital in this endeavor and in many cases their contribution is to provide a framework for acknowledging the limitations of our knowledge. Some of the empirical regularities that were cited in CLM have not stood the test of time, or at least they had to be qualified and their limitations acknowledged. This makes it hard to give a clear and simple picture that one could explain to a teenager.

This book is intended to be used as a text for advanced undergraduates and graduate students in economics, finance, statistics, mathematics, and engineering who are interested in financial applications and the methodology needed to understand and interpret those applications. I have taught part of this material at Yale University, the London School of Economics, the University of Cambridge, Humboldt University, Shandong University, SHUFE, and Renmin University. I provide two introductory chapters on financial institutions, financial economics, and econometrics, which provide some essential background that will be drawn on in later chapters. The main material begins with the efficient markets hypothesis and the predictability of asset returns, which is a central question of financial economics. I provide some updates on the empirical regularities found in CLM. I then provide a separate chapter on robust methods, which are important because large observations such as the October 1987 stock market crash can have an undue influence on estimation and hypothesis tests. I then cover some topics in market microstructure, which is a very active area struggling with new developments in market structure, technology, and regulation. I cover the classical topics of stale and discrete prices as well as the models for adverse selection and market impact that form the language of this area. I use some matrix algebra in Chapters 6 to 8; it is hard if not impossible to present this material cogently without these tools, and to understand big data without the basics of linear algebra is like trying to assemble an IKEA cupboard in the dark without an Allen key. Luckily there are many excellent books that provide suitable coverage of the necessary material, for example Linton (2016). The material on event studies has been expanded to include recent work coming from microeconometrics that can be used to evaluate the effects of policy changes on outcomes other than stock returns. I also include the standard methodology based on the market model but provide a more detailed discussion of the effects of overlapping estimation and event windows. I cover the CAPM next with some discussion of portfolio grouping methods and the two main testing methodologies. The chapter on multifactor models covers the main approaches including the Fama–French approach, which was still in its early days when CLM was published but is now one of the dominant methodologies. I also cover statistical factor models and characteristic based models. The next two chapters consider some intertemporal asset pricing material and the associated econometrics such as predictive regressions, volatility tests, and generalized method of moments (GMM). The chapter on volatility describes the three main approaches to measuring and defining volatility based on option prices, high frequency data, and dynamic time series modelling. The chapter on continuous time models develops some of this material further, but also introduces the models and methods widely used in this area. I cover some material on yield curve estimation and its application to pricing. The final chapter considers risk management including extreme value theory and dynamic modelling approaches. I use a number of datasets of different frequencies in the book to illustrate various points and to report on the main features of financial data. As usual, results can vary.

I have included short biographies of authors who have influenced me regarding financial econometrics particularly. My prediction is that at least one of them will win the Nobel Prize in economics.

The book contains many terms in bold face, which can then be investigated further by internet search. I have provided some computer code in different languages, such as MATLAB, GAUSS, and R, pertinent to various parts of the book. I am told that STATA can accomplish many things, but I have yet to see the light. A lot of analysis can be done by EVIEWS, and I provide a short introduction to its use in handling daily stock return data. I also provide a link to a number of data sources that can help with student projects and the like.

Acknowledgments

No man is an island, and I would like to thank the people who have had an influence on my research career. Even though they may not have been directly involved in the development of this book, I have drawn heavily on my interactions with them throughout this project. In roughly chronological order they are: Haya Friedman, Jan Magnus, Tom Rothenberg, Jens Perch Nielsen, Peter Bickel, Greg Connor, Peter Robinson, Wolfgang Härdle, Enno Mammen, Per Mykland, Miguel Delgado, Neil Shephard, Don Andrews, Peter Phillips, Xiaohong Chen, Arthur Lewbel, Yoon-Jae Whang, Zhijie Xiao, Christian Hafner, Frank Diebold, Eric Ghysels, Jean-Marie Dufour, Haim Levy, Andrew Patton, Jiti Gao, Jon Danielsson, Jean-Pierre Zigrand, Alexei Onatskiy, Andrew Harvey, Andrew Chesher, Hashem Pesaran, Richard Smith, and Mark Salmon. I would like also to thank my current and former PhD and Master's students who have contributed to the development of this book. I would like to thank Greg Connor, Katja Smetanina, and anonymous referees for comments.

Notation and Conventions

In this book I use the dating convention yyyymmddhhmmss. A visiting time traveller would surely prefer to know the year before the month or day, although he might ask why we have we have chosen 24 hours in a day and 60 minutes in an hour, etc. I use $\xrightarrow{P}$ to denote convergence in probability and $\Longrightarrow$ to denote convergence in distribution. $\log(x)$ is the natural logarithm unless otherwise stated. $\mathbb{R}$ is the set of real numbers, $'$ denotes differentiation, and $^\intercal$ denotes matrix transpose. We use $X_n = O(n)$ to mean that X_n/n is bounded for a deterministic sequence X_n. I use $\simeq$ to generically denote an approximation and $\sim$ to mean to have the same distribution as. I do not have a bracketing convention like some journals, but I do have a preference for round curved brackets over square ones. Dollars or \$ are US unless otherwise specified.