PRINCIPLES OF ECONOMETRICS

5th Edition

R. CARTER HILL | WILLIAM E. GRIFFITHS | GUAY C. LIM

WILEY

Principles of Econometrics

Fifth Edition

R. CARTER HILL
Louisiana State University

WILLIAM E. GRIFFITHS
University of Melbourne

GUAY C. LIM
University of Melbourne

WILEY

EDITORIAL DIRECTOR	Michael McDonald
EXECUTIVE EDITOR	Lise Johnson
CHANNEL MARKETING MANAGER	Michele Szczesniak
CONTENT ENABLEMENT SENIOR MANAGER	Leah Michael
CONTENT MANAGEMENT DIRECTOR	Lisa Wojcik
CONTENT MANAGER	Nichole Urban
SENIOR CONTENT SPECIALIST	Nicole Repasky
PRODUCTION EDITOR	Abidha Sulaiman
COVER PHOTO CREDIT	© liuzishan/iStockphoto

This book was set in STIX-Regular 10/12pt by SPi Global and printed and bound by Strategic Content Imaging.

This book is printed on acid free paper. ∞

Founded in 1807, John Wiley & Sons, Inc. has been a valued source of knowledge and understanding for more than 200 years, helping people around the world meet their needs and fulfill their aspirations. Our company is built on a foundation of principles that include responsibility to the communities we serve and where we live and work. In 2008, we launched a Corporate Citizenship Initiative, a global effort to address the environmental, social, economic, and ethical challenges we face in our business. Among the issues we are addressing are carbon impact, paper specifications and procurement, ethical conduct within our business and among our vendors, and community and charitable support. For more information, please visit our website: www.wiley.com/go/citizenship.

ISBN: 9781118452271 (PBK)
ISBN: 9781119320951 (EVALC)

Library of Congress Cataloging-in-Publication Data

Names: Hill, R. Carter, author. | Griffiths, William E., author. | Lim, G. C. (Guay C.), author.
Title: Principles of econometrics / R. Carter Hill, Louisiana State University, William E. Griffiths, University of Melbourne, Guay C. Lim, University of Melbourn.
Description: Fifth Edition. | Hoboken : Wiley, 2017. | Revised edition of the authors' Principles of econometrics, c2011. | Includes bibliographical references and index. |
Identifiers: LCCN 2017043094 (print) | LCCN 2017056927 (ebook) | ISBN 9781119342854 (pdf) | ISBN 9781119320944 (epub) | ISBN 9781118452271 (paperback) | ISBN 9781119320951 (eval copy)
Subjects: LCSH: Econometrics. | BISAC: BUSINESS & ECONOMICS / Econometrics.
Classification: LCC HB139 (ebook) | LCC HB139 .H548 2018 (print) | DDC 330.01/5195—dc23
LC record available at https://lccn.loc.gov/2017043094

The inside back cover will contain printing identification and country of origin if omitted from this page. In addition, if the ISBN on the back cover differs from the ISBN on this page, the one on the back cover is correct.

10 9 8 7 6 5 4 3 2 1

Carter Hill dedicates this work to his wife, Melissa Waters
Bill Griffiths dedicates this work to Jill, David, and Wendy Griffiths
Guay Lim dedicates this work to Tony Meagher

Brief Contents

Preface

Principles of Econometrics, *Fifth Edition*, is an introductory book for undergraduate students in economics and finance, as well as first-year graduate students in economics, finance, accounting, agricultural economics, marketing, public policy, sociology, law, forestry, and political science. We assume that students have taken courses in the principles of economics and elementary statistics. Matrix algebra is not used, and we introduce and develop calculus concepts in an Appendix. The title *Principles of Econometrics* emphasizes our belief that econometrics should be part of the economics curriculum, in the same way as the principles of microeconomics and the principles of macroeconomics. Those who have been studying and teaching econometrics as long as we have will remember that *Principles of Econometrics* was the title that Henri Theil used for his 1971 classic, which was also published by John Wiley & Sons. Our choice of the same title is not intended to signal that our book is similar in level and content. Theil's work was, and remains, a unique treatise on advanced graduate level econometrics. Our book is an introductory level econometrics text.

Book Objectives

Principles of Econometrics is designed to give students an understanding of why econometrics is necessary and to provide them with a working knowledge of basic econometric tools so that

i. They can apply these tools to modeling, estimation, inference, and forecasting in the context of real-world economic problems.
ii. They can evaluate critically the results and conclusions from others who use basic econometric tools.
iii. They have a foundation and understanding for further study of econometrics.
iv. They have an appreciation of the range of more advanced techniques that exist and that may be covered in later econometric courses.

The book is neither an econometrics cookbook nor is it in a theorem-proof format. It emphasizes motivation, understanding, and implementation. Motivation is achieved by introducing very simple economic models and asking economic questions that the student can answer. Understanding is aided by lucid description of techniques, clear interpretation, and appropriate applications. Learning is reinforced by doing, with clear worked examples in the text and exercises at the end of each chapter.

Overview of Contents

This fifth edition is a major revision in format and content. The chapters contain core material and exercises, while appendices contain more advanced material. Chapter examples are now identified and separated from other content so that they may be easily referenced. From the beginning, we recognize the observational nature of most economic data and modify modeling assumptions accordingly. Chapter 1 introduces econometrics and gives general guidelines for writing an empirical research paper and locating economic data sources. The Probability Primer preceding Chapter 2 summarizes essential properties of random variables and their probability distributions and reviews summation notation. The simple linear regression model is covered in Chapters 2–4, while the multiple regression model is treated in Chapters 5–7. Chapters 8 and 9 introduce econometric problems that are unique to cross-sectional data (heteroskedasticity) and time-series data

(dynamic models), respectively. Chapters 10 and 11 deal with endogenous regressors, the failure of least squares when a regressor is endogenous, and instrumental variables estimation, first in the general case, and then in the simultaneous equations model. In Chapter 12, the analysis of time-series data is extended to discussions of nonstationarity and cointegration. Chapter 13 introduces econometric issues specific to two special time-series models, the vector error correction, and vector autoregressive models, while Chapter 14 considers the analysis of volatility in data and the ARCH model. In Chapters 15 and 16, we introduce microeconometric models for panel data and qualitative and limited dependent variables. In appendices A, B, and C, we introduce math, probability, and statistical inference concepts that are used in the book.

Summary of Changes and New Material

This edition includes a great deal of new material, including new examples and exercises using real data and some significant reorganizations. In this edition, we number examples for easy reference and offer 25–30 new exercises in each chapter. Important new features include

- Chapter 1 includes a discussion of data types and sources of economic data on the Internet. Tips on writing a research paper are given "up front" so that students can form ideas for a paper as the course develops.
- A Probability Primer precedes Chapter 2. This Primer reviews the concepts of random variables and how probabilities are calculated from probability density functions. Mathematical expectation and rules of expected values are summarized for discrete random variables. These rules are applied to develop the concepts of variance and covariance. Calculations of probabilities using the normal distribution are illustrated. New material includes sections on conditional expectation, conditional variance, iterated expectations, and the bivariate normal distribution.
- Chapter 2 now starts with a discussion of causality. We define the population regression function and discuss exogeneity in considerable detail. The properties of the ordinary least squares (OLS) estimator are examined within the framework of the new assumptions. New appendices have been added on the independent variable, covering the various assumptions that might be made about the sampling process, derivations of the properties of the OLS estimator, and Monte Carlo experiments to numerically illustrate estimator properties.
- In Chapter 3, we note that hypothesis test mechanics remain the same under the revised assumptions because test statistics are "pivotal," meaning that their distributions under the null hypothesis do not depend on the data. In appendices, we add an extended discussion of test behavior under the alternative, introduce the noncentral t-distribution, and illustrate test power. We also include new Monte Carlo experiments illustrating test properties when the explanatory variable is random.
- Chapter 4 discusses in detail nonlinear relationships such as the log-log, log-linear, linear-log, and polynomial models. We have expanded the discussion of diagnostic residual plots and added sections on identifying influential observations. The familiar concepts of compound interest are used to motivate several log-linear models. We add an appendix on the concept of mean squared error and the minimum mean squared error predictor.
- Chapter 5 introduces multiple regression in the random-x framework. The Frisch–Waugh–Lovell (FWL) theorem is introduced as a way to help understand interpretation of the multiple regression model and used throughout the remainder of the book. Discussions of the properties of the OLS estimator, and interval estimates and t-tests, are updated. The large sample properties of the OLS estimator, and the delta method, are now introduced within the chapter rather than an appendix. Appendices provide further discussion and Monte Carlo

properties to illustrate the delta method. We provide a new appendix on bootstrapping and its uses.

- Chapter 6 adds a new section on large sample tests. We explain the use of control variables and the difference between causal and predictive models. We revise the discussion of collinearity and include a discussion of influential observations. We introduce nonlinear regression models and nonlinear least squares algorithms are discussed. Appendices are added to discuss the statistical power of F-tests and further uses of the Frisch–Waugh–Lovell theorem.
- Chapter 7 now includes an extensive section on treatment effects and causal modeling in Rubin's potential outcomes framework. We explain and illustrate the interesting regression discontinuity design. An appendix includes a discussion of the important "overlap" assumption.
- Chapter 8 has been reorganized so that the heteroskedasticity robust variance of the OLS estimator appears before testing. We add a section on how model specification can ameliorate heteroskedasticity in some applications. We add appendices to explain the properties of the OLS residuals and another to explain alternative robust sandwich variance estimators. We present Monte Carlo experiments to illustrate the differences.
- Chapter 9 has been reorganized and streamlined. The initial section introduces the different ways that dynamic elements can be added to the regression model. These include using finite lag models, infinite lag models, and autoregressive errors. We carefully discuss autocorrelations, including testing for autocorrelation and representing autocorrelations using a correlogram. After introducing the concepts of stationarity and weak dependence, we discuss the general notions of forecasting and forecast intervals in the context of autoregressive distributed lag (ARDL) models. Following these introductory concepts, there are details of estimating and using alternative models, covering such topics as choosing lag lengths, testing for Granger causality, the Lagrange multiplier test for serial correlation, and using models for policy analysis. We provide very specific sets of assumptions for time-series regression models and outline how heteroskedastic and autocorrelation consistent, robust, standard errors are used. We discuss generalized least squares estimation of a time-series regression model and its relation to nonlinear least squares regression. A detailed discussion of the infinite lag model and how to use multiplier analysis is provided. An appendix contains details of the Durbin–Watson test.
- Chapter 10 on endogeneity problems has been streamlined because the concept of random explanatory variables is now introduced much earlier in the book. We provide further analysis of weak instruments and how weak instruments adversely affect the precision of IV estimation. The details of the Hausman test are now included in the chapter.
- Chapter 11 now adds Klein's Model I as an example.
- Chapter 12 includes more details of deterministic trends and unit roots. The section on unit root testing has been restructured so that each Dickey–Fuller test is more fully explained and illustrated with an example. Numerical examples of ARDL models with nonstationary variables that are, and are not, cointegrated have been added.
- The data in Chapter 13 have been updated and new exercises added.
- Chapter 14 mentions further extensions of ARCH volatility models.
- Chapter 15 has been restructured to give priority to how panel data can be used to cope with the endogeneity caused by unobserved heterogeneity. We introduce the advantages of having panel data using the first difference estimator, and then discuss the within/fixed effects estimator. We provide an extended discussion of cluster robust standard errors in both the OLS and fixed effects model. We discuss the Mundlak version of the Hausman test for endogeneity. We give brief mention to how to extend the use of panel data in several ways.

- The Chapter 16 discussion of binary choice models is reorganized and expanded. It now includes brief discussions of advanced topics such as binary choice models with endogenous explanatory variables and binary choice models with panel data. We add new appendices on random utility models and latent variable models.
- Appendix A includes new sections on second derivatives and finding maxima and minima of univariate and bivariate functions.
- Appendix B includes new material on conditional expectations and conditional variances, including several useful decompositions. We include new sections on truncated random variables, including the truncated normal and Poisson distributions. To facilitate discussions of test power, we have new sections on the noncentral t-distribution, the noncentral Chi-square distribution, and the noncentral F-distribution. We have included an expanded new section on the log-normal distribution.
- Appendix C content does not change a great deal, but 20 new exercises are included.
- Statistical Tables for the Standard Normal cumulative distribution function, the t-distribution and Chi-square distribution critical values for selected percentiles, the F-distribution critical values for the 95th and 99th percentiles, and the Standard Normal density function values appear in Appendix D.
- A useful "cheat sheet" of essential formulas is provided at the authors' website, www.principlesofeconometrics.com, rather than inside the covers as in the previous edition.

For Instructors: Suggested Course Plans

Principles of Econometrics, Fifth Edition is suitable for one or two semester courses at the undergraduate or first year graduate level. Some suitable plans for alternative courses are as follows:

- One-semester survey course: Sections P.1–P.6.2 and P.7; Sections 2.1–2.9; Chapters 3 and 4; Sections 5.1–5.6; Sections 6.1–6.5; Sections 7.1–7.3; Sections 8.1–8.4 and 8.6; Sections 9.1–9.4.2 and 9.5–9.5.1.
- One-semester survey course enhancements for Master's or Ph.D.: Include Appendices for Chapters 2–9.
- Two-semester survey second course, cross-section emphasis: Section P.6; Section 2.10; Section 5.7; Section 6.6; Sections 7.4–7.6; Sections 8.5 and 8.6.3–8.6.5; Sections 10.1–10.4; Sections 15.1–15.4; Sections 16.1–16.2 and 16.6;
- Two-semester survey second course, time series emphasis: Section P.6; Section 2.10; Section 5.7; Section 6.6; Sections 7.4–7.6; Sections 8.5 and 8.6.3–8.6.5; Section 9.5; Sections 10.1–10.4; Sections 12.1–12.5; Sections 13.1–13.5; Sections 14.1–14.4;
- Two-semester survey course enhancements for Master's or Ph.D.: Include Appendices from Chapters 10, Chapter 11, Appendices 15A–15B, Sections 16.3–16.5 and 16.7, Appendices 16A–16D, Book Appendices B and C.

Computer Supplement Books

There are several computer supplements to *Principles of Econometrics, Fifth Edition*. The supplements are not versions of the text and cannot substitute for the text. They use the examples in the text as a vehicle for learning the software. We show how to use the software to get the answers for each example in the text.

- *Using EViews for the Principles of Econometrics, Fifth Edition,* by William E. Griffiths, R. Carter Hill, and Guay C. Lim [ISBN 9781118469842]. This supplementary book presents the EViews 10 [www.eviews.com] software commands required for the examples in *Principles of Econometrics* in a clear and concise way. It includes many illustrations that are student friendly. It is useful not only for students and instructors who will be using this software as part of their econometrics course but also for those who wish to learn how to use EViews.
- *Using Stata for the Principles of Econometrics, Fifth Edition*, by Lee C. Adkins and R. Carter Hill [ISBN 9781118469873]. This supplementary book presents the Stata 15.0 [www.stata.com] software commands required for the examples in *Principles of Econometrics*. It is useful not only for students and instructors who will be using this software as part of their econometrics course but also for those who wish to learn how to use Stata. Screen shots illustrate the use of Stata's drop-down menus. Stata commands are explained and the use of "do-files" illustrated.
- *Using SAS for the Principles of Econometrics, Fifth Edition*, by Randall C. Campbell and R. Carter Hill [ISBN 9781118469880]. This supplementary book gives SAS 9.4 [www.sas.com] software commands for econometric tasks, following the general outline of *Principles of Econometrics, Fifth Edition*. It includes enough background material on econometrics so that instructors using any textbook can easily use this book as a supplement. The volume spans several levels of econometrics. It is suitable for undergraduate students who will use "canned" SAS statistical procedures, and for graduate students who will use advanced procedures as well as direct programming in SAS's matrix language; the latter is discussed in chapter appendices.
- *Using Excel for Principles of Econometrics, Fifth Edition,* by Genevieve Briand and R. Carter Hill [ISBN 9781118469835]. This supplement explains how to use Excel to reproduce most of the examples in *Principles of Econometrics*. Detailed instructions and screen shots are provided explaining both the computations and clarifying the operations of Excel. Templates are developed for common tasks.
- *Using GRETL for Principles of Econometrics, Fifth Edition*, by Lee C. Adkins. This free supplement, readable using Adobe Acrobat, explains how to use the freely available statistical software GRETL (download from http://gretl.sourceforge.net). Professor Adkins explains in detail, and using screen shots, how to use GRETL to replicate the examples in *Principles of Econometrics.* The manual is freely available at www.learneconometrics.com/gretl.html.
- *Using R for Principles of Econometrics, Fifth Edition*, by Constantin Colonescu and R. Carter Hill. This free supplement, readable using Adobe Acrobat, explains how to use the freely available statistical software *R* (download from https://www.r-project.org/). The supplement explains in detail, and using screen shots, how to use *R* to replicate the examples in *Principles of Econometrics, Fifth Edition.* The manual is freely available at https://bookdown.org/ccolonescu/RPOE5/.

Data Files

Data files for the book are provided in a variety of formats at the book website www.wiley.com/college/hill. These include

- ASCII format (*.dat). These are text files containing only data.
- Definition files (*.def). These are text files describing the data file contents, with a listing of variable names, variable definitions, and summary statistics.
- EViews (*.wf1) workfiles for each data file.
- Excel (*.xls) workbooks for each data file, including variable names in the first row.

- Comma separated values (*.csv) files that can be read into almost all software.
- Stata (*.dta) data files.
- SAS (*.sas7bdat) data files.
- GRETL (*.gdt) data files.
- R (*.rdata) data files.

The author website www.principlesofeconometrics.com includes a complete list of the data files and where they are used in the book.

Additional Resources

The book website www.principlesofeconometrics.com includes

- Individual data files in each format as well as ZIP files containing data in compressed format.
- Book errata.
- Brief answers to odd number problems. These answers are also provided on the book website at www.wiley.com/college/hill.
- Additional examples with solutions. Some extra examples come with complete solutions so that students will know what a good answer looks like.
- Tips on writing research papers.

Resources for Instructors

For instructors, also available at the website www.wiley.com/college/hill are

- Complete solutions, in both Microsoft Word and *.pdf formats, to *all* exercises in the text.
- PowerPoint slides and PowerPoint Viewer.

Acknowledgments

Authors Hill and Griffiths want to acknowledge the gifts given to them over the past 40 years by mentor, friend, and colleague George Judge. Neither this book nor any of the other books we have shared in the writing of would have ever seen the light of day without his vision and inspiration.

We also wish to give thanks to the many students and faculty who have commented on the fourth edition of the text and contributed to the fifth edition. This list includes Alejandra Breve Ferrari, Alex James, Alyssa Wans, August Saibeni, Barry Rafferty, Bill Rising, Bob Martin, Brad Lewis, Bronson Fong, David Harris, David Iseral, Deborah Williams, Deokrye Baek, Diana Whistler, Emma Powers, Ercan Saridogan, Erdogan Cevher, Erika Haguette, Ethan Luedecke, Gareth Thomas, Gawon Yoon, Genevieve Briand, German Altgelt, Glenn Sueyoshi, Henry McCool, James Railton, Jana Ruimerman, Jeffery Parker, Joe Goss, John Jackson, Julie Leiby, Katharina Hauck, Katherine Ramirez, Kelley Pace, Lee Adkins, Matias Cattaneo, Max O'Krepki, Meagan McCollum, Micah West, Michelle Savolainen, Oystein Myrland, Patrick Scholten, Randy Campbell, Regina Riphahn, Sandamali Kankanamge, Sergio Pastorello, Shahrokh Towfighi, Tom Fomby, Tong Zeng, Victoria Pryor, Yann Nicolas, and Yuanbo Zhang. In the book errata we acknowledge those who have pointed out our errors.

R. Carter Hill
William E. Griffiths
Guay C. Lim

Table of Contents

List of Examples