Principles of

# ECONOMETRICS

*Fourth Edition*

## INTERNATIONAL STUDENT VERSION

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

# Principles of Econometrics

Fourth Edition

**International Student version**

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## The Rules of Summation

$$\sum_{i=1}^{n} x_i = x_1 + x_2 + \cdots + x_n$$

$$\sum_{i=1}^{n} a = na$$

$$\sum_{i=1}^{n} ax_i = a\sum_{i=1}^{n} x_i$$

$$\sum_{i=1}^{n} (x_i + y_i) = \sum_{i=1}^{n} x_i + \sum_{i=1}^{n} y_i$$

$$\sum_{i=1}^{n} (ax_i + by_i) = a\sum_{i=1}^{n} x_i + b\sum_{i=1}^{n} y_i$$

$$\sum_{i=1}^{n} (a + bx_i) = na + b\sum_{i=1}^{n} x_i$$

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

$$\sum_{i=1}^{n} (x_i - \bar{x}) = 0$$

$$\sum_{i=1}^{2}\sum_{j=1}^{3} f(x_i, y_j) = \sum_{i=1}^{2} [f(x_i, y_1) + f(x_i, y_2) + f(x_i, y_3)]$$
$$= f(x_1, y_1) + f(x_1, y_2) + f(x_1, y_3)$$
$$+ f(x_2, y_1) + f(x_2, y_2) + f(x_2, y_3)$$

## Expected Values & Variances

$$E(X) = x_1 f(x_1) + x_2 f(x_2) + \cdots + x_n f(x_n)$$
$$= \sum_{i=1}^{n} x_i f(x_i) = \sum_{x} x f(x)$$

$$E[g(X)] = \sum_{x} g(x) f(x)$$

$$E[g_1(X) + g_2(X)] = \sum_{x} [g_1(x) + g_2(x)] f(x)$$
$$= \sum_{x} g_1(x) f(x) + \sum_{x} g_2(x) f(x)$$
$$= E[g_1(X)] + E[g_2(X)]$$

$E(c) = c$
$E(cX) = cE(X)$
$E(a + cX) = a + cE(X)$
$\text{var}(X) = \sigma^2 = E[X - E(X)]^2 = E(X^2) - [E(X)]^2$
$\text{var}(a + cX) = E[(a + cX) - E(a + cX)]^2 = c^2\text{var}(X)$

## Marginal and Conditional Distributions

$f(x) = \sum_{y} f(x, y)$ for each value $X$ can take

$f(y) = \sum_{x} f(x, y)$ for each value $Y$ can take

$$f(x|y) = P[X = x|Y = y] = \frac{f(x, y)}{f(y)}$$

If $X$ and $Y$ are independent random variables, then $f(x,y) = f(x)f(y)$ for each and every pair of values $x$ and $y$. The converse is also true.

If $X$ and $Y$ are independent random variables, then the conditional probability density function of $X$ given that

$$Y = y \text{ is } f(x|y) = \frac{f(x, y)}{f(y)} = \frac{f(x)f(y)}{f(y)} = f(x)$$

for each and every pair of values $x$ and $y$. The converse is also true.

## Expectations, Variances & Covariances

$$\text{cov}(X, Y) = E[(X - E[X])(Y - E[Y])]$$
$$= \sum_{x}\sum_{y} [x - E(X)][y - E(Y)] f(x, y)$$

$$\rho = \frac{\text{cov}(X,Y)}{\sqrt{\text{var}(X)\text{var}(Y)}}$$

$E(c_1X + c_2Y) = c_1E(X) + c_2E(Y)$
$E(X + Y) = E(X) + E(Y)$
$\text{var}(aX + bY + cZ) = a^2\text{var}(X) + b^2\text{var}(Y) + c^2\text{var}(Z)$
$+ 2ab\text{cov}(X,Y) + 2ac\text{cov}(X,Z) + 2bc\text{cov}(Y,Z)$

If $X$, $Y$, and $Z$ are independent, or uncorrelated, random variables, then the covariance terms are zero and:

$$\text{var}(aX + bY + cZ) = a^2\text{var}(X) + b^2\text{var}(Y) + c^2\text{var}(Z)$$

## Normal Probabilities

If $X \sim N(\mu, \sigma^2)$, then $Z = \dfrac{X - \mu}{\sigma} \sim N(0, 1)$

If $X \sim N(\mu, \sigma^2)$ and $a$ is a constant, then

$$P(X \geq a) = P\left(Z \geq \frac{a - \mu}{\sigma}\right)$$

If $X \sim N(\mu, \sigma^2)$ and $a$ and $b$ are constants, then

$$P(a \leq X \leq b) = P\left(\frac{a-\mu}{\sigma} \leq Z \leq \frac{b - \mu}{\sigma}\right)$$

## Assumptions of the Simple Linear Regression Model

| | |
|---|---|
| SR1 | The value of $y$, for each value of $x$, is $y = \beta_1 + \beta_2 x + e$ |
| SR2 | The average value of the random error $e$ is $E(e) = 0$ since we assume that $E(y) = \beta_1 + \beta_2 x$ |
| SR3 | The variance of the random error $e$ is $\text{var}(e) = \sigma^2 = \text{var}(y)$ |
| SR4 | The covariance between any pair of random errors, $e_i$ and $e_j$ is $\text{cov}(e_i, e_j) = \text{cov}(y_i, y_j) = 0$ |
| SR5 | The variable $x$ is not random and must take at least two different values. |
| SR6 | (*optional*) The values of $e$ are *normally distributed* about their mean $e \sim N(0, \sigma^2)$ |

## Least Squares Estimation

If $b_1$ and $b_2$ are the least squares estimates, then

$$\hat{y}_i = b_1 + b_2 x_i$$
$$\hat{e}_i = y_i - \hat{y}_i = y_i - b_1 - b_2 x_i$$

### The Normal Equations

$$Nb_1 + \Sigma x_i b_2 = \Sigma y_i$$
$$\Sigma x_i b_1 + \Sigma x_i^2 b_2 = \Sigma x_i y_i$$

### Least Squares Estimators

$$b_2 = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})}{\Sigma (x_i - \bar{x})^2}$$
$$b_1 = \bar{y} - b_2\bar{x}$$

*Carter Hill dedicates this work to his wife, Melissa Waters*

*Bill Griffiths dedicates this work to JoAnn, Jill, David, Wendy, Nina, and Isabella*

*Guay Lim dedicates this work to Tony Meagher*

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# Preface

*Principles of Econometrics*, 4th edition, is an introductory book for undergraduate students in economics and finance, as well as for first-year graduate students in economics, finance, accounting, agricultural economics, marketing, public policy, sociology, law, and political science. It is assumed that students have taken courses in the principles of economics, and elementary statistics. Matrix algebra is not used, and calculus concepts are introduced and developed in the appendices.

A brief explanation of the title is in order. This work is a revision of *Principles of Econometrics*, 3rd edition, by Hill, Griffiths, and Lim (Wiley, 2008), which was a revision of *Undergraduate Econometrics*, 2nd edition, by Hill, Griffiths, and Judge (Wiley, 2001). The earlier title was chosen to clearly differentiate the book from other more advanced books by the same authors. We made the title change because the book is appropriate not only for undergraduates, but also for first-year graduate students in many fields, as well as MBA students. Furthermore, naming it *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 and 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

- They can apply these tools to modeling, estimation, inference, and forecasting in the context of real-world economic problems.
- They can evaluate critically the results and conclusions from others who use basic econometric tools.
- They have a foundation and understanding for further study of econometrics.
- 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 *not* 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 fourth edition retains the spirit and basic structure of the third edition. Chapter 1 introduces econometrics and gives general guidelines for writing an empirical research paper and for 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 random 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. 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.
- The Probability Primer precedes Chapter 2. This primer reviews the concepts of random variables, and how probabilities are calculated given probability density functions. Mathematical expectation and rules of expected values are summarized for discrete random variables. These rules are applied to develop the concept of variance and covariance. Calculations of probabilities using the normal distribution are illustrated.
- Chapter 2 is expanded to include brief introductions to nonlinear relationships and the concept of an indicator (or dummy) variable. A new section has been added on interpreting a standard error. An appendix has been added on Monte Carlo simulation and is used to illustrate the sampling properties of the least squares estimator.
- Estimation and testing of linear combinations of parameters is now included in Chapter 3. An appendix is added using Monte Carlo simulation to illustrate the properties of interval estimators and hypothesis tests. Chapter 4 discusses in detail nonlinear relationships such as the log-log, log-linear, linear-log, and polynomial models. Model interpretations are discussed and examples given, along with an introduction to residual analysis.
- The introductory chapter on multiple regression (Chapter 5) now includes material on standard errors for both linear and nonlinear functions of coefficients, and how they are used for interval estimation and hypothesis testing. The treatment of

polynomial and log-linear models given in Chapter 4 is extended to the multiple regression model; interaction variables are included and marginal effects are described. An appendix on large sample properties of estimators has been added.

- Chapter 6 contains a new section on model selection criteria and a reorganization of material on the $F$-test for joint hypotheses.
- Chapter 7 now deals exclusively with indicator variables. In addition to the standard material, we introduce the linear probability model and treatment effect models, including difference and difference-in-difference estimators.
- Chapter 8 has been reorganized so that testing for heteroskedasticity precedes estimation with heteroskedastic errors. A section on heteroskedasticity in the linear probability model has been added.
- Chapter 9 on regression with stationary time series data has been restructured to emphasize autoregressive distributed lag models and their special cases: finite distributed lags, autoregressive models, and the AR(1) error model. Testing for serial correlation using the correlogram and Lagrange multiplier tests now precedes estimation. Two new macroeconomic examples, Okun's law and the Phillips curve, are used to illustrate the various models. Sections on exponential smoothing and model selection criteria have been added, and the section on multiplier analysis has been expanded.
- Chapter 10 on endogeneity problems has been streamlined, using real data examples in the body of the chapter as illustrations. New material on assessing instrument strength has been added. An appendix on testing for weak instruments introduces the Stock-Yogo critical values for the Cragg-Donald $F$-test. A Monte Carlo experiment is included to demonstrate the properties of instrumental variables estimators.
- Chapter 11 now includes an appendix describing two alternatives to two-stage least squares: the limited information maximum likelihood and the $k$-class estimators. The Stock-Yogo critical values for LIML and $k$-class estimator are provided. Monte Carlo results illustrate the properties of LIML and the $k$-class estimator.
- Chapter 12 now contains a section on the derivation of the short-run error correction model.
- Chapter 13 now contains an example and exercise using data which includes the recent global financial crisis.
- Chapter 14 now contains a revised introduction to the ARCH model.
- Chapter 15 has been restructured to give more prominence to the fixed effects and random effects models. New sections on cluster-robust standard errors and the Hausman-Taylor estimator have been added.
- Chapter 16 includes more on post-estimation analysis within choice models. The average marginal effect is explained and illustrated. The "delta method" is used to create standard errors of estimated marginal effects and predictions. An appendix gives algebraic detail on the "delta method."
- Appendix A now introduces the concepts of derivatives and integrals. Rules for derivatives are given, and the Taylor series approximation explained. Both derivatives and integrals are explained intuitively using graphs and algebra, with each in separate sections.
- Appendix B includes a discussion and illustration of the properties of both discrete and continuous random variables. Extensive examples are given, including integration techniques for continuous random variables. The change-of-variable technique for deriving the probability density function of a function of a continuous random variable is discussed. The method of inversion for drawing

random values is discussed and illustrated. Linear congruential generators for uniform random numbers are described.

- Appendix C now includes a section on kernel density estimation.
- Brief answers to selected problems, along with all data files, will now be included on the book website at www.wiley.com/college/hill.

## Computer Supplement Books

The following books are offered by John Wiley and Sons as computer supplements to *Principles of Econometrics*:

- *Using EViews for Principles of Econometrics,* 4th edition, by Griffiths, Hill and Lim [ISBN 978-1-11803207-7 or at www.coursesmart.com]. This supplementary book presents the EViews 7.1 [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 Principles of Econometrics*, 4th edition, by Adkins and Hill [ISBN 978-1-11803208-4 or at www.coursesmart.com]. This supplementary book presents the Stata 11.1 [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 Econometrics* by Hill and Campbell [ISBN 978-1-11803209-1 or at www.coursesmart.com]. This stand-alone book gives SAS 9.2 [www.sas.com] software commands for econometric tasks, following the general outline of *Principles of Econometrics*. 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*, 4th edition, by Briand and Hill [ISBN 978-1-11803210-7 or at www.coursesmart.com]. 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*, 4th edition, by 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, 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.

## Resources for Students

Available at both the Book Companion Site for the International Student Version, and at the author website, principlesofeconometrics.com, are

- Data files
- Answers to selected exercises

## Data Files

Data files for the book are provided in a variety of formats at the Book Companion Site. 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 2007 (*.xlsx) workbooks for each data file, including variable names in the first row
- Stata (*.dta) data files
- SAS (*.sas7bdat) data files
- GRETL (*.gdt) data files

## Resources for Instructors

For instructors, also available at the Book Companion Site are

- An Instructor's Resources Guide with complete solutions, in both Microsoft Word and *.pdf formats, to *all* exercises in the text
- PowerPoint Presentation Slides
- Supplementary exercises with solutions

## Author Website

The authors' website—principlesofeconometrics.com—includes

- Individual data files in each format, as well as Zip files containing data in compressed format
- Book errata
- Links to other useful websites, including RATS and SHAZAM computer resources for *Principles of Econometrics*, and tips on writing research papers
- Answers to selected exercises
- Hints and resources for writing

## Acknowledgments

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years. Individuals who have pointed out errors of one sort or another are recognized in the errata listed at principlesofeconometrics.com.

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