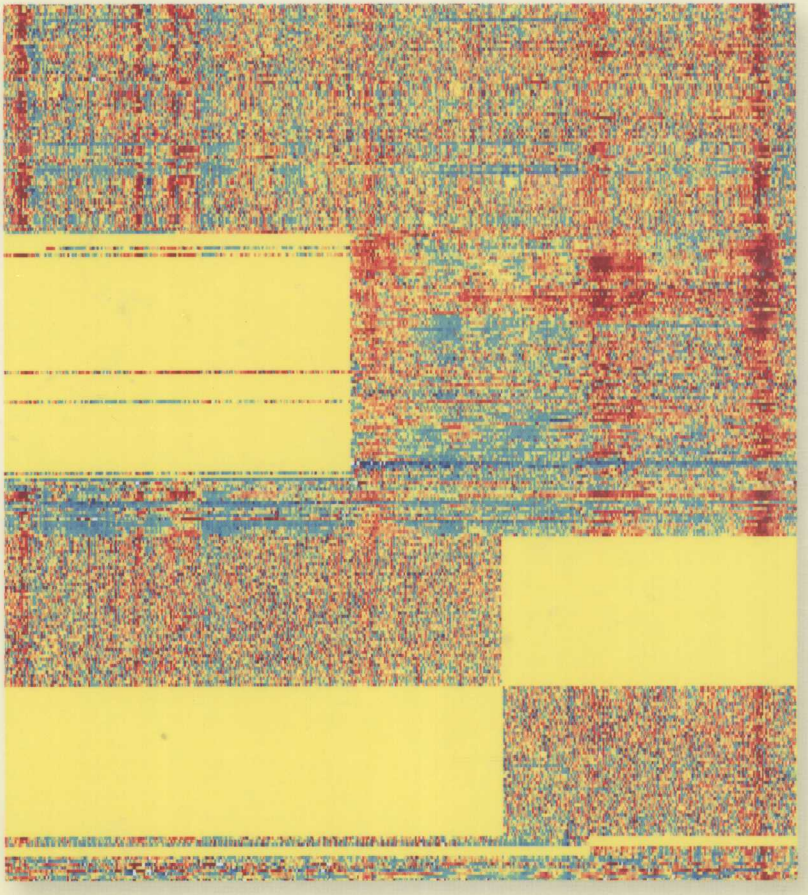
INTRODUCTION TO ECONOMETRICS

THIRD EDITION



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Introduction to Econometrics

THIRD EDITION

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Preface

Econometrics can be a fun course for both teacher and student. The real world of economics, business, and government is a complicated and messy place, full of competing ideas and questions that demand answers. Is it more effective to tackle drunk driving by passing tough laws or by increasing the tax on alcohol? Can you make money in the stock market by buying when prices are historically low, relative to earnings, or should you just sit tight as the random walk theory of stock prices suggests? Can we improve elementary education by reducing class sizes, or should we simply have our children listen to Mozart for 10 minutes a day? Econometrics helps us sort out sound ideas from crazy ones and find quantitative answers to important quantitative questions. Econometrics opens a window on our complicated world that lets us see the relationships on which people, businesses, and governments base their decisions.

Introduction to Econometrics is designed for a first course in undergraduate econometrics. It is our experience that to make econometrics relevant in an introductory course, interesting applications must motivate the theory and the theory must match the applications. This simple principle represents a significant departure from the older generation of econometrics books, in which theoretical models and assumptions do not match the applications. It is no wonder that some students question the relevance of econometrics after they spend much of their time learning assumptions that they subsequently realize are unrealistic so that they must then learn "solutions" to "problems" that arise when the applications do not match the assumptions. We believe that it is far better to motivate the need for tools with a concrete application and then to provide a few simple assumptions that match the application. Because the theory is immediately relevant to the applications, this approach can make econometrics come alive.

New to This Edition

- Updated treatment of standard errors for panel data regression
- Discussion of when and why missing data can present a problem for regression analysis
- The use of regression discontinuity design as a method for analyzing quasi-experiments

- Updated discussion of weak instruments
- Discussion of the use and interpretation of control variables integrated into the core development of regression analysis
- Introduction of the "potential outcomes" framework for experimental data
- Additional general interest boxes
- Additional exercises, both pencil-and-paper and empirical

This third edition builds on the philosophy of the first and second editions that applications should drive the theory, not the other way around.

One substantial change in this edition concerns inference in regression with panel data (Chapter 10). In panel data, the data within an entity typically are correlated over time. For inference to be valid, standard errors must be computed using a method that is robust to this correlation. The chapter on panel data now uses one such method, clustered standard errors, from the outset. Clustered standard errors are the natural extension to panel data of the heteroskedasticity-robust standard errors introduced in the initial treatment of regression analysis in Part II. Recent research has shown that clustered standard errors have a number of desirable properties, which are now discussed in Chapter 10 and in a revised appendix to Chapter 10.

Another substantial set of changes concerns the treatment of experiments and quasi-experiments in Chapter 13. The discussion of differences-in-differences regression has been streamlined and draws directly on the multiple regression principles introduced in Part II. Chapter 13 now discusses regression discontinuity design, which is an intuitive and important framework for the analysis of quasi-experimental data. In addition, Chapter 13 now introduces the potential outcomes framework and relates this increasingly commonplace terminology to concepts that were introduced in Parts I and II.

This edition has a number of other significant changes. One is incorporating a precise but accessible treatment of control variables into the initial discussion of multiple regression. Chapter 7 now discusses conditions for control variables being successful in the sense that the coefficient on the variable of interest is unbiased even though the coefficients on the control variables generally are not. Other changes include a new discussion of missing data in Chapter 9, a new optional calculus-based appendix to Chapter 8 on slopes and elasticities of nonlinear regression functions, and an updated discussion in Chapter 12 of what to do if you have weak instruments. This edition also includes new general-interest boxes, updated empirical examples, and additional exercises.

Features of This Book

Introduction to Econometrics differs from other textbooks in three main ways. First, we integrate real-world questions and data into the development of the theory, and we take seriously the substantive findings of the resulting empirical analysis. Second, our choice of topics reflects modern theory and practice. Third, we provide theory and assumptions that match the applications. Our aim is to teach students to become sophisticated consumers of econometrics and to do so at a level of mathematics appropriate for an introductory course.

Real-World Questions and Data

We organize each methodological topic around an important real-world question that demands a specific numerical answer. For example, we teach single-variable regression, multiple regression, and functional form analysis in the context of estimating the effect of school inputs on school outputs. (Do smaller elementary school class sizes produce higher test scores?) We teach panel data methods in the context of analyzing the effect of drunk driving laws on traffic fatalities. We use possible racial discrimination in the market for home loans as the empirical application for teaching regression with a binary dependent variable (logit and probit). We teach instrumental variable estimation in the context of estimating the demand elasticity for cigarettes. Although these examples involve economic reasoning, all can be understood with only a single introductory course in economics, and many can be understood without any previous economics coursework. Thus the instructor can focus on teaching econometrics, not microeconomics or macroeconomics.

We treat all our empirical applications seriously and in a way that shows students how they can learn from data but at the same time be self-critical and aware of the limitations of empirical analyses. Through each application, we teach students to explore alternative specifications and thereby to assess whether their substantive findings are robust. The questions asked in the empirical applications are important, and we provide serious and, we think, credible answers. We encourage students and instructors to disagree, however, and invite them to reanalyze the data, which are provided on the textbook's Companion Website (**http://www.pearsonhighered.com/stock_watson**).

Contemporary Choice of Topics

Econometrics has come a long way since the 1980s. The topics we cover reflect the best of contemporary applied econometrics. One can only do so much in an

introductory course, so we focus on procedures and tests that are commonly used in practice. For example:

- ***Instrumental variables regression.*** We present instrumental variables regression as a general method for handling correlation between the error term and a regressor, which can arise for many reasons, including omitted variables and simultaneous causality. The two assumptions for a valid instrument—exogeneity and relevance—are given equal billing. We follow that presentation with an extended discussion of where instruments come from and with tests of overidentifying restrictions and diagnostics for weak instruments, and we explain what to do if these diagnostics suggest problems.
- ***Program evaluation.*** An increasing number of econometric studies analyze either randomized controlled experiments or quasi-experiments, also known as natural experiments. We address these topics, often collectively referred to as program evaluation, in Chapter 13. We present this research strategy as an alternative approach to the problems of omitted variables, simultaneous causality, and selection, and we assess both the strengths and the weaknesses of studies using experimental or quasi-experimental data.
- ***Forecasting.*** The chapter on forecasting (Chapter 14) considers univariate (autoregressive) and multivariate forecasts using time series regression, not large simultaneous equation structural models. We focus on simple and reliable tools, such as autoregressions and model selection via an information criterion, that work well in practice. This chapter also features a practically oriented treatment of stochastic trends (unit roots), unit root tests, tests for structural breaks (at known and unknown dates), and pseudo out-of-sample forecasting, all in the context of developing stable and reliable time series forecasting models.
- ***Time series regression.*** We make a clear distinction between two very different applications of time series regression: forecasting and estimation of dynamic causal effects. The chapter on causal inference using time series data (Chapter 15) pays careful attention to when different estimation methods, including generalized least squares, will or will not lead to valid causal inferences and when it is advisable to estimate dynamic regressions using OLS with heteroskedasticity- and autocorrelation-consistent standard errors.

Theory That Matches Applications

Although econometric tools are best motivated by empirical applications, students need to learn enough econometric theory to understand the strengths and limitations of those tools. We provide a modern treatment in which the fit between

theory and applications is as tight as possible, while keeping the mathematics at a level that requires only algebra.

Modern empirical applications share some common characteristics: The data sets typically are large (hundreds of observations, often more); regressors are not fixed over repeated samples but rather are collected by random sampling (or some other mechanism that makes them random); the data are not normally distributed; and there is no *a priori* reason to think that the errors are homoskedastic (although often there are reasons to think that they are heteroskedastic).

These observations lead to important differences between the theoretical development in this textbook and other textbooks.

- ***Large-sample approach.*** Because data sets are large, from the outset we use large-sample normal approximations to sampling distributions for hypothesis testing and confidence intervals. Our experience is that it takes less time to teach the rudiments of large-sample approximations than to teach the Student t and exact F distributions, degrees-of-freedom corrections, and so forth. This large-sample approach also saves students the frustration of discovering that, because of nonnormal errors, the exact distribution theory they just mastered is irrelevant. Once taught in the context of the sample mean, the large-sample approach to hypothesis testing and confidence intervals carries directly through multiple regression analysis, logit and probit, instrumental variables estimation, and time series methods.
- ***Random sampling.*** Because regressors are rarely fixed in econometric applications, from the outset we treat data on all variables (dependent and independent) as the result of random sampling. This assumption matches our initial applications to cross-sectional data, it extends readily to panel and time series data, and because of our large-sample approach it poses no additional conceptual or mathematical difficulties.
- ***Heteroskedasticity.*** Applied econometricians routinely use heteroskedasticity-robust standard errors to eliminate worries about whether heteroskedasticity is present or not. In this book, we move beyond treating heteroskedasticity as an exception or a "problem" to be "solved"; instead, we allow for heteroskedasticity from the outset and simply use heteroskedasticity-robust standard errors. We present homoskedasticity as a special case that provides a theoretical motivation for OLS.

Skilled Producers, Sophisticated Consumers

We hope that students using this book will become sophisticated consumers of empirical analysis. To do so, they must learn not only how to use the tools of

regression analysis, but also how to assess the validity of empirical analyses presented to them.

Our approach to teaching how to assess an empirical study is threefold. First, immediately after introducing the main tools of regression analysis, we devote Chapter 9 to the threats to internal and external validity of an empirical study. This chapter discusses data problems and issues of generalizing findings to other settings. It also examines the main threats to regression analysis, including omitted variables, functional form misspecification, errors-in-variables, selection, and simultaneity—and ways to recognize these threats in practice.

Second, we apply these methods for assessing empirical studies to the empirical analysis of the ongoing examples in the book. We do so by considering alternative specifications and by systematically addressing the various threats to validity of the analyses presented in the book.

Third, to become sophisticated consumers, students need firsthand experience as producers. Active learning beats passive learning, and econometrics is an ideal course for active learning. For this reason, the textbook Web site features data sets, software, and suggestions for empirical exercises of differing scopes.

Approach to Mathematics and Level of Rigor

Our aim is for students to develop a sophisticated understanding of the tools of modern regression analysis, whether the course is taught at a "high" or a "low" level of mathematics. Parts I through IV of the text (which cover the substantive material) are accessible to students with only precalculus mathematics. Parts I through IV have fewer equations, and more applications, than many introductory econometrics books and far fewer equations than books aimed at mathematical sections of undergraduate courses. But more equations do not imply a more sophisticated treatment. In our experience, a more mathematical treatment does not lead to a deeper understanding for most students.

That said, different students learn differently, and for the mathematically well-prepared students, learning can be enhanced by a more explicitly mathematical treatment. Part V therefore contains an introduction to econometric theory that is appropriate for students with a stronger mathematical background. We believe that, when the mathematical chapters in Part V are used in conjunction with the material in Parts I through IV, this book is suitable for advanced undergraduate or master's level econometrics courses.

Contents and Organization

There are five parts to the *Introduction to Econometrics*. This textbook assumes that the student has had a course in probability and statistics, although we review that material in Part I. We cover the core material of regression analysis in Part II. Parts III, IV, and V present additional topics that build on the core treatment in Part II.

Part I

Chapter 1 introduces econometrics and stresses the importance of providing quantitative answers to quantitative questions. It discusses the concept of causality in statistical studies and surveys the different types of data encountered in econometrics. Material from probability and statistics is reviewed in Chapters 2 and 3, respectively; whether these chapters are taught in a given course or are simply provided as a reference depends on the background of the students.

Part II

Chapter 4 introduces regression with a single regressor and ordinary least squares (OLS) estimation, and Chapter 5 discusses hypothesis tests and confidence intervals in the regression model with a single regressor. In Chapter 6, students learn how they can address omitted variable bias using multiple regression, thereby estimating the effect of one independent variable while holding other independent variables constant. Chapter 7 covers hypothesis tests, including F-tests, and confidence intervals in multiple regression. In Chapter 8, the linear regression model is extended to models with nonlinear population regression functions, with a focus on regression functions that are linear in the parameters (so that the parameters can be estimated by OLS). In Chapter 9, students step back and learn how to identify the strengths and limitations of regression studies, seeing in the process how to apply the concepts of internal and external validity.

Part III

Part III presents extensions of regression methods. In Chapter 10, students learn how to use panel data to control for unobserved variables that are constant over time. Chapter 11 covers regression with a binary dependent variable. Chapter 12 shows how instrumental variables regression can be used to address a variety of problems that produce correlation between the error term and the regressor, and

examines how one might find and evaluate valid instruments. Chapter 13 introduces students to the analysis of data from experiments and quasi-, or natural, experiments, topics often referred to as "program evaluation."

Part IV

Part IV takes up regression with time series data. Chapter 14 focuses on forecasting and introduces various modern tools for analyzing time series regressions such as unit root tests and tests for stability. Chapter 15 discusses the use of time series data to estimate causal relations. Chapter 16 presents some more advanced tools for time series analysis, including models of conditional heteroskedasticity.

Part V

Part V is an introduction to econometric theory. This part is more than an appendix that fills in mathematical details omitted from the text. Rather, it is a self-contained treatment of the econometric theory of estimation and inference in the linear regression model. Chapter 17 develops the theory of regression analysis for a single regressor; the exposition does not use matrix algebra, although it does demand a higher level of mathematical sophistication than the rest of the text. Chapter 18 presents and studies the multiple regression model, instrumental variables regression, and generalized method of moments estimation of the linear model, all in matrix form.

Prerequisites Within the Book

Because different instructors like to emphasize different material, we wrote this book with diverse teaching preferences in mind. To the maximum extent possible, the chapters in Parts III, IV, and V are "stand-alone" in the sense that they do not require first teaching all the preceding chapters. The specific prerequisites for each chapter are described in Table I. Although we have found that the sequence of topics adopted in the textbook works well in our own courses, the chapters are written in a way that allows instructors to present topics in a different order if they so desire.

Sample Courses

This book accommodates several different course structures.

TABLE I Guide to Prerequisites for Special-Topic Chapters in Parts III, IV, and V

	Prerequisite parts or chapters								
	Part I	Part II		Part III		Part IV			Part V
Chapter	1–3	4–7, 9	8	10.1, 10.2	12.1, 12.2	14.1–14.4	14.5–14.8	15	17
10	X[a]	X[a]	X						
11	X[a]	X[a]	X						
12.1, 12.2	X[a]	X[a]	X						
12.3-12.6	X[a]	X[a]	X	X	X				
13	X[a]	X[a]	X	X	X				
14	X[a]	X[a]	[b]						
15	X[a]	X[a]	[b]			X			
16	X[a]	X[a]	[b]			X	X	X	
17	X	X	X						
18	X	X	X		X				X

This table shows the minimum prerequisites needed to cover the material in a given chapter. For example, estimation of dynamic causal effects with time series data (Chapter 15) first requires Part I (as needed, depending on student preparation, and except as noted in footnote a), Part II (except for chapter 8; see footnote b), and Sections 14.1 through 14.4.

[a]Chapters 10 through 16 use exclusively large-sample approximations to sampling distributions, so the optional Sections 3.6 (the Student t distribution for testing means) and 5.6 (the Student t distribution for testing regression coefficients) can be skipped.
[b]Chapters 14 through 16 (the time series chapters) can be taught without first teaching Chapter 8 (nonlinear regression functions) if the instructor pauses to explain the use of logarithmic transformations to approximate percentage changes.

Standard Introductory Econometrics

This course introduces econometrics (Chapter 1) and reviews probability and statistics as needed (Chapters 2 and 3). It then moves on to regression with a single regressor, multiple regression, the basics of functional form analysis, and the evaluation of regression studies (all Part II). The course proceeds to cover regression with panel data (Chapter 10), regression with a limited dependent variable (Chapter 11), and instrumental variables regression (Chapter 12), as time permits. The course concludes with experiments and quasi-experiments in Chapter 13, topics that provide an opportunity to return to the questions of estimating causal effects raised at the beginning of the semester and to recapitulate core regression methods. *Prerequisites: Algebra II and introductory statistics.*

Introductory Econometrics with Time Series and Forecasting Applications

Like the standard introductory course, this course covers all of Part I (as needed) and Part II. Optionally, the course next provides a brief introduction to panel data (Sections 10.1 and 10.2) and takes up instrumental variables regression (Chapter 12, or just Sections 12.1 and 12.2). The course then proceeds to Part IV, covering forecasting (Chapter 14) and estimation of dynamic causal effects (Chapter 15). If time permits, the course can include some advanced topics in time series analysis such as volatility clustering and conditional heteroskedasticity (Section 16.5). *Prerequisites: Algebra II and introductory statistics.*

Applied Time Series Analysis and Forecasting

This book also can be used for a short course on applied time series and forecasting, for which a course on regression analysis is a prerequisite. Some time is spent reviewing the tools of basic regression analysis in Part II, depending on student preparation. The course then moves directly to Part IV and works through forecasting (Chapter 14), estimation of dynamic causal effects (Chapter 15), and advanced topics in time series analysis (Chapter 16), including vector autoregressions and conditional heteroskedasticity. An important component of this course is hands-on forecasting exercises, available to instructors on the book's accompanying Web site. *Prerequisites: Algebra II and basic introductory econometrics or the equivalent.*

Introduction to Econometric Theory

This book is also suitable for an advanced undergraduate course in which the students have a strong mathematical preparation or for a master's level course in econometrics. The course briefly reviews the theory of statistics and probability as necessary (Part I). The course introduces regression analysis using the nonmathematical, applications-based treatment of Part II. This introduction is followed by the theoretical development in Chapters 17 and 18 (through Section 18.5). The course then takes up regression with a limited dependent variable (Chapter 11) and maximum likelihood estimation (Appendix 11.2). Next, the course optionally turns to instrumental variables regression and generalized method of moments (Chapter 12 and Section 18.7), time series methods (Chapter 14), and the estimation of causal effects using time series data and generalized least squares (Chapter 15 and Section 18.6). *Prerequisites: Calculus and introductory statistics. Chapter 18 assumes previous exposure to matrix algebra.*

Pedagogical Features

This textbook has a variety of pedagogical features aimed at helping students understand, retain, and apply the essential ideas. *Chapter introductions* provide a real-world grounding and motivation, as well as a brief road map highlighting the sequence of the discussion. *Key terms* are boldfaced and defined in context throughout each chapter, and *Key Concept boxes* at regular intervals recap the central ideas. *General interest boxes* provide interesting excursions into related topics and highlight real-world studies that use the methods or concepts being discussed in the text. A *Summary* concluding each chapter serves as a helpful framework for reviewing the main points of coverage. The questions in the *Review the Concepts* section check students' understanding of the core content, *Exercises* give more intensive practice working with the concepts and techniques introduced in the chapter, and *Empirical Exercises* allow students to apply what they have learned to answer real-world empirical questions. At the end of the textbook, the *Appendix* provides statistical tables, the *References* section lists sources for further reading, and a *Glossary* conveniently defines many key terms in the book.

Supplements to Accompany the Textbook

The online supplements accompanying the third edition of *Introduction to Econometrics* include the Solutions Manual, Test Item File (by Manfred W. Keil of Claremont McKenna College), and PowerPoint® slides with text figures, tables, and Key Concepts. The Solutions Manual includes solutions to all the end-of-chapter exercises, while the Test Item File, offered in Test Generator Software (TestGen with QuizMaster), provides a rich supply of easily edited test problems and questions of various types to meet specific course needs. These resources are available for download from the Instructor's Resource Center at **http://www.pearsonhighered.com/stock_watson**.

In addition, a Companion Website, found at **http://www.pearsonhighered.com/stock_watson/**, provides a wide range of additional resources for students and faculty. They include data sets for in-text empirical exercises, data sets for replicating empirical results, replication files for empirical results reported in the text, practice quizzes, answers to end-of-chapter Review the Concepts questions and odd-numbered Exercises, and tutorials.

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