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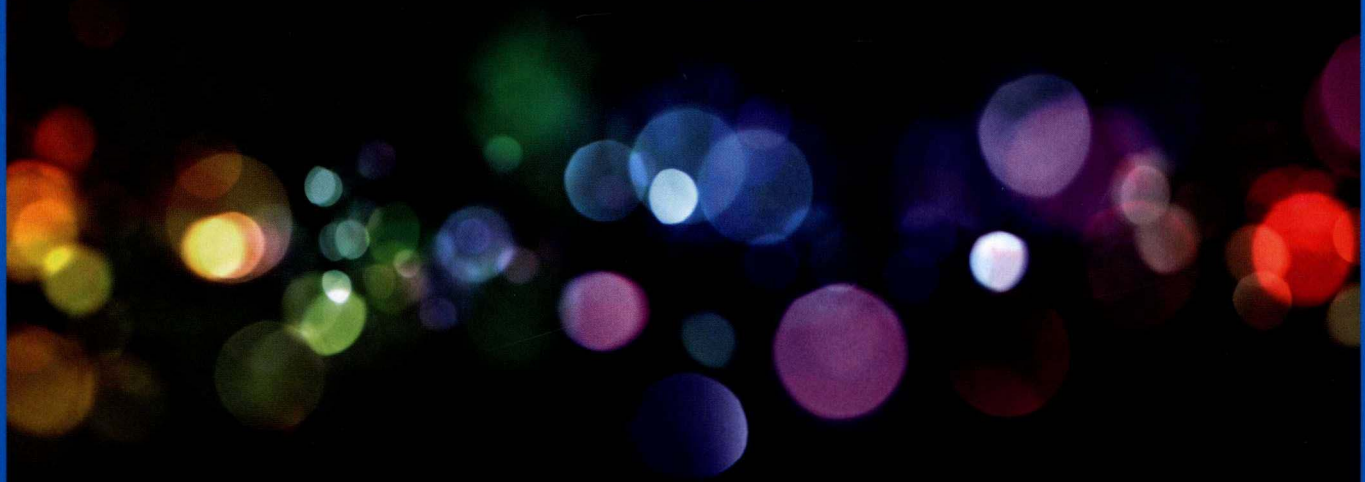
A Modern Approach 7e



Jeffrey M. Wooldridge

Introductory Econometrics

A MODERN APPROACH

SEVENTH EDITION

Jeffrey M. Wooldridge
Michigan State University

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***Introductory Econometrics: A Modern Approach,* Seventh Edition**
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Preface

My motivation for writing the first edition of *Introductory Econometrics: A Modern Approach* was that I saw a fairly wide gap between how econometrics is taught to undergraduates and how empirical researchers think about and apply econometric methods. I became convinced that teaching introductory econometrics from the perspective of professional users of econometrics would actually simplify the presentation, in addition to making the subject much more interesting.

Based on the positive reactions to the several earlier editions, it appears that my hunch was correct. Many instructors, having a variety of backgrounds and interests and teaching students with different levels of preparation, have embraced the modern approach to econometrics espoused in this text. The emphasis in this edition is still on applying econometrics to real-world problems. Each econometric method is motivated by a particular issue facing researchers analyzing nonexperimental data. The focus in the main text is on understanding and interpreting the assumptions in light of actual empirical applications: the mathematics required is no more than college algebra and basic probability and statistics.

Designed for Today's Econometrics Course

The seventh edition preserves the overall organization of the sixth. The most noticeable feature that distinguishes this text from most others is the separation of topics by the kind of data being analyzed. This is a clear departure from the traditional approach, which presents a linear model, lists all assumptions that may be needed at some future point in the analysis, and then proves or asserts results without clearly connecting them to the assumptions. My approach is first to treat, in Part 1, multiple regression analysis with cross-sectional data, under the assumption of random sampling. This setting is natural to students because they are familiar with random sampling from a population in their introductory statistics courses. Importantly, it allows us to distinguish assumptions made about the underlying population regression model—assumptions that can be given economic or behavioral content—from assumptions about how the data were sampled. Discussions about the consequences of nonrandom sampling can be treated in an intuitive fashion after the students have a good grasp of the multiple regression model estimated using random samples.

An important feature of a modern approach is that the explanatory variables—along with the dependent variable—are treated as outcomes of random variables. For the social sciences, allowing random explanatory variables is much more realistic than the traditional assumption of nonrandom explanatory variables. As a nontrivial benefit, the population model/random sampling approach reduces the number of assumptions that students must absorb and understand. Ironically, the classical approach to regression analysis, which treats the explanatory variables as fixed in repeated samples and is still pervasive in introductory texts, literally applies to data collected in an experimental setting. In addition, the contortions required to state and explain assumptions can be confusing to students.

My focus on the population model emphasizes that the fundamental assumptions underlying regression analysis, such as the zero mean assumption on the unobservable error term, are properly

stated conditional on the explanatory variables. This leads to a clear understanding of the kinds of problems, such as heteroskedasticity (nonconstant variance), that can invalidate standard inference procedures. By focusing on the population, I am also able to dispel several misconceptions that arise in econometrics texts at all levels. For example, I explain why the usual R-squared is still valid as a goodness-of-fit measure in the presence of heteroskedasticity (Chapter 8) or serially correlated errors (Chapter 12); I provide a simple demonstration that tests for functional form should not be viewed as general tests of omitted variables (Chapter 9); and I explain why one should always include in a regression model extra control variables that are uncorrelated with the explanatory variable of interest, which is often a key policy variable (Chapter 6).

Because the assumptions for cross-sectional analysis are relatively straightforward yet realistic, students can get involved early with serious cross-sectional applications without having to worry about the thorny issues of trends, seasonality, serial correlation, high persistence, and spurious regression that are ubiquitous in time series regression models. Initially, I figured that my treatment of regression with cross-sectional data followed by regression with time series data would find favor with instructors whose own research interests are in applied microeconomics, and that appears to be the case. It has been gratifying that adopters of the text with an applied time series bent have been equally enthusiastic about the structure of the text. By postponing the econometric analysis of time series data, I am able to put proper focus on the potential pitfalls in analyzing time series data that do not arise with cross-sectional data. In effect, time series econometrics finally gets the serious treatment it deserves in an introductory text.

As in the earlier editions, I have consciously chosen topics that are important for reading journal articles and for conducting basic empirical research. Within each topic, I have deliberately omitted many tests and estimation procedures that, while traditionally included in textbooks, have not withstood the empirical test of time. Likewise, I have emphasized more recent topics that have clearly demonstrated their usefulness, such as obtaining test statistics that are robust to heteroskedasticity (or serial correlation) of unknown form, using multiple years of data for policy analysis, or solving the omitted variable problem by instrumental variables methods. I appear to have made fairly good choices, as I have received only a handful of suggestions for adding or deleting material.

I take a systematic approach throughout the text, by which I mean that each topic is presented by building on the previous material in a logical fashion, and assumptions are introduced only as they are needed to obtain a conclusion. For example, empirical researchers who use econometrics in their research understand that not all of the Gauss-Markov assumptions are needed to show that the ordinary least squares (OLS) estimators are unbiased. Yet the vast majority of econometrics texts introduce a complete set of assumptions (many of which are redundant or in some cases even logically conflicting) before proving the unbiasedness of OLS. Similarly, the normality assumption is often included among the assumptions that are needed for the Gauss-Markov Theorem, even though it is fairly well known that normality plays no role in showing that the OLS estimators are the best linear unbiased estimators.

My systematic approach is illustrated by the order of assumptions that I use for multiple regression in Part 1. This structure results in a natural progression for briefly summarizing the role of each assumption:

MLR.1: Introduce the population model and interpret the population parameters (which we hope to estimate).

MLR.2: Introduce random sampling from the population and describe the data that we use to estimate the population parameters.

MLR.3: Add the assumption on the explanatory variables that allows us to compute the estimates from our sample; this is the so-called no perfect collinearity assumption.

MLR.4: Assume that, in the population, the mean of the unobservable error does not depend on the values of the explanatory variables; this is the "mean independence" assumption combined with a zero population mean for the error, and it is the key assumption that delivers unbiasedness of OLS.

After introducing Assumptions MLR.1 to MLR.3, one can discuss the algebraic properties of ordinary least squares—that is, the properties of OLS for a particular set of data. By adding Assumption MLR.4, we can show that OLS is unbiased (and consistent). Assumption MLR.5 (homoskedasticity) is added for the Gauss-Markov Theorem and for the usual OLS variance formulas to be valid. Assumption MLR.6 (normality), which is not introduced until Chapter 4, is added to round out the classical linear model assumptions. The six assumptions are used to obtain exact statistical inference and to conclude that the OLS estimators have the smallest variances among all unbiased estimators.

I use parallel approaches when I turn to the study of large-sample properties and when I treat regression for time series data in Part 2. The careful presentation and discussion of assumptions makes it relatively easy to transition to Part 3, which covers advanced topics that include using pooled cross-sectional data, exploiting panel data structures, and applying instrumental variables methods. Generally, I have strived to provide a unified view of econometrics, where all estimators and test statistics are obtained using just a few intuitively reasonable principles of estimation and testing (which, of course, also have rigorous justification). For example, regression-based tests for heteroskedasticity and serial correlation are easy for students to grasp because they already have a solid understanding of regression. This is in contrast to treatments that give a set of disjointed recipes for outdated econometric testing procedures.

Throughout the text, I emphasize ceteris paribus relationships, which is why, after one chapter on the simple regression model, I move to multiple regression analysis. The multiple regression setting motivates students to think about serious applications early. I also give prominence to policy analysis with all kinds of data structures. Practical topics, such as using proxy variables to obtain ceteris paribus effects and interpreting partial effects in models with interaction terms, are covered in a simple fashion.

Designed at Undergraduates, Applicable to Master's Students

The text is designed for undergraduate economics majors who have taken college algebra and one-semester of introductory probability and statistics. (Math Refresher A, B, and C contain the requisite background material.) A one-semester or one-quarter econometrics course would not be expected to cover all, or even any, of the more advanced material in Part 3. A typical introductory course includes Chapters 1 through 8, which cover the basics of simple and multiple regression for cross-sectional data. Provided the emphasis is on intuition and interpreting the empirical examples, the material from the first eight chapters should be accessible to undergraduates in most economics departments. Most instructors will also want to cover at least parts of the chapters on regression analysis with time series data, Chapters 10 and 12, in varying degrees of depth. In the one-semester course that I teach at Michigan State, I cover Chapter 10 fairly carefully, give an overview of the material in Chapter 11, and cover the material on serial correlation in Chapter 12. I find that this basic one-semester course puts students on a solid footing to write empirical papers, such as a term paper, a senior seminar paper, or a senior thesis. Chapter 9 contains more specialized topics that arise in analyzing cross-sectional data, including data problems such as outliers and nonrandom sampling; for a one-semester course, it can be skipped without loss of continuity.

The structure of the text makes it ideal for a course with a cross-sectional or policy analysis focus: the time series chapters can be skipped in lieu of topics from Chapters 9 or 15. The new material on potential outcomes added to the first nine chapters should help the instructor craft a course that provides an introduction to modern policy analysis. Chapter 13 is advanced only in the sense that it treats two new data structures: independently pooled cross sections and two-period panel data analysis. Such data structures are especially useful for policy analysis, and the chapter provides

several examples. Students with a good grasp of Chapters 1 through 8 will have little difficulty with Chapter 13. Chapter 14 covers more advanced panel data methods and would probably be covered only in a second course. A good way to end a course on cross-sectional methods is to cover the rudiments of instrumental variables estimation in Chapter 15.

I have used selected material in Part 3, including Chapters 13 and 17, in a senior seminar geared to producing a serious research paper. Along with the basic one-semester course, students who have been exposed to basic panel data analysis, instrumental variables estimation, and limited dependent variable models are in a position to read large segments of the applied social sciences literature. Chapter 17 provides an introduction to the most common limited dependent variable models.

The text is also well suited for an introductory master's level course, where the emphasis is on applications rather than on derivations using matrix algebra. Several instructors have used the text to teach policy analysis at the master's level. For instructors wanting to present the material in matrix form, Appendices D and E are self-contained treatments of the matrix algebra and the multiple regression model in matrix form.

At Michigan State, PhD students in many fields that require data analysis—including accounting, agricultural economics, development economics, economics of education, finance, international economics, labor economics, macroeconomics, political science, and public finance—have found the text to be a useful bridge between the empirical work that they read and the more theoretical econometrics they learn at the PhD level.

Suggestions for Designing Your Course Beyond the Basic

I have already commented on the contents of most of the chapters as well as possible outlines for courses. Here I provide more specific comments about material in chapters that might be covered or skipped:

Chapter 9 has some interesting examples (such as a wage regression that includes IQ score as an explanatory variable). The rubric of proxy variables does not have to be formally introduced to present these kinds of examples, and I typically do so when finishing up cross-sectional analysis. In Chapter 12, for a one-semester course, I skip the material on serial correlation robust inference for ordinary least squares as well as dynamic models of heteroskedasticity.

Even in a second course I tend to spend only a little time on Chapter 16, which covers simultaneous equations analysis. I have found that instructors differ widely in their opinions on the importance of teaching simultaneous equations models to undergraduates. Some think this material is fundamental; others think it is rarely applicable. My own view is that simultaneous equations models are overused (see Chapter 16 for a discussion). If one reads applications carefully, omitted variables and measurement error are much more likely to be the reason one adopts instrumental variables estimation, and this is why I use omitted variables to motivate instrumental variables estimation in Chapter 15. Still, simultaneous equations models are indispensable for estimating demand and supply functions, and they apply in some other important cases as well.

Chapter 17 is the only chapter that considers models inherently nonlinear in their parameters, and this puts an extra burden on the student. The first material one should cover in this chapter is on probit and logit models for binary response. My presentation of Tobit models and censored regression still appears to be novel in introductory texts. I explicitly recognize that the Tobit model is applied to corner solution outcomes on random samples, while censored regression is applied when the data collection process censors the dependent variable at essentially arbitrary thresholds.

Chapter 18 covers some recent important topics from time series econometrics, including testing for unit roots and cointegration. I cover this material only in a second-semester course at either the undergraduate or master's level. A fairly detailed introduction to forecasting is also included in Chapter 18.

Chapter 19, which would be added to the syllabus for a course that requires a term paper, is much more extensive than similar chapters in other texts. It summarizes some of the methods appropriate for various kinds of problems and data structures, points out potential pitfalls, explains in some detail how to write a term paper in empirical economics, and includes suggestions for possible projects.

What's Changed?

I have added new exercises to many chapters, including to the Math Refresher and Advanced Treatment appendices. Some of the new computer exercises use new data sets, including a data set on performance of men's college basketball teams. I have also added more challenging problems that require derivations.

There are several notable changes to the text. An important organizational change, which should facilitate a wider variety of teaching tastes, is that the notion of binary, or dummy, explanatory variables is introduced in Chapter 2. There, it is shown that ordinary least squares estimation leads to a staple in basic statistics: the difference in means between two subgroups in a population. By introducing qualitative factors into regression early on, the instructor is able to use a wider variety of empirical examples from the very beginning.

The early discussion of binary explanatory variables allows for a formal introduction of potential, or counterfactual, outcomes, which is indispensable in the modern literature on estimating causal effects. The counterfactual approach to studying causality appears in previous editions, but Chapters 2, 3, 4, and 7 now explicitly include new sections on the modern approach to causal inference. Because basic policy analysis involves the binary decision to participate in a program or not, a leading example of using dummy independent variables in simple and multiple regression is to evaluate policy interventions. At the same time, the new material is incorporated into the text so that instructors not wishing to cover the potential outcomes framework may easily skip the material. Several end-of-chapter problems concern extensions of the basic potential outcomes framework, which should be valuable for instructors wishing to cover that material.

Chapter 3 includes a new section on different ways that one can apply multiple regression, including problems of pure prediction, testing efficient markets, and culminating with a discussion of estimating treatment or causal effects. I think this section provides a nice way to organize students' thinking about the scope of multiple regression after they have seen the mechanics of ordinary least squares (OS) and several examples. As with other new material that touches on causal effects, this material can be skipped without loss of continuity. A new section in Chapter 7 continues the discussion of potential outcomes, allowing for nonconstant treatment effects. The material is a nice illustration of estimating different regression functions for two subgroups from a population. New problems in this chapter that allow the student more experience in using full regression adjustment to estimate causal effects.

One notable change to Chapter 9 is a more detailed discussion of using missing data indicators when data are missing on one or more of the explanatory variables. The assumptions underlying the method are discussed in more detail than in the previous edition.

Chapter 12 has been reorganized to reflect a more modern treatment of the problem of serial correlation in the errors of time series regression models. The new structure first covers adjusting the OLS standard errors to allow general forms of serial correlation. Thus, the chapter outline now parallels that in Chapter 8, with the emphasis in both cases on OLS estimation but making inference robust to violation of standard assumptions. Correcting for serial correlation using generalized least squares now comes after OLS and the treatment of testing for serial correlation.

The advanced chapters also include several improvements. Chapter 13 now discusses, at an accessible level, extensions of the standard difference-in-differences setup, allowing for multiple control

groups, multiple time periods, and even group-specific trends. In addition, the chapter includes a more detailed discussion of computing standard errors robust to serial correlation when using first-differencing estimation with panel data.

Chapter 14 now provides more detailed discussions of several important issues in estimating panel data models by fixed effects, random effects, and correlated random effects (CRE). The CRE approach with missing data is discussed in more detail, as is how one accounts for general functional forms, such as squares and interactions, which are covered in the cross-sectional setting in Chapter 6. An expanded section on general policy analysis with panel data should be useful for courses with an emphasis on program interventions and policy evaluation.

Chapter 16, which still covers simultaneous equations models, now provides an explicit link between the potential outcomes framework and specification of simultaneous equations models.

Chapter 17 now includes a discussion of using regression adjustment for estimating causal (treatment) effects when the outcome variable has special features, such as when the outcome itself is a binary variable. Then, as the reader is asked to explore in a new problem, logit and probit models can be used to obtain more reliable estimates of average treatment effects by estimating separate models for each treatment group.

Chapter 18 now provides more details about how one can compute a proper standard error for a forecast (as opposed to a prediction) interval. This should help the advanced reader understand in more detail the nature of the uncertainty in the forecast.

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Design Features

In addition to the didactic material in the chapter, I have included two features to help students better understand and apply what they are learning. Each chapter contains many numbered examples. Several of these are case studies drawn from recently published papers. I have used my judgment to simplify the analysis, hopefully without sacrificing the main point. The "Going Further Questions" in

the chapter provide students an opportunity to "go further" in learning the material through analysis or application. Students will find immediate feedback for these questions in the end of the text.

The end-of-chapter problems and computer exercises are heavily oriented toward empirical work, rather than complicated derivations. The students are asked to reason carefully based on what they have learned. The computer exercises often expand on the in-text examples. Several exercises use data sets from published works or similar data sets that are motivated by published research in economics and other fields.

A pioneering feature of this introductory econometrics text is the extensive glossary. The short definitions and descriptions are a helpful refresher for students studying for exams or reading empirical research that uses econometric methods. I have added and updated several entries for the seventh edition.

Instructional Tools

Cengage offers various supplements for instructors and students who use this book. I would like to thank the Subject Matter Expert team who worked on these supplements and made teaching and learning easy.

C. Patrick Scott, Ph.D., Louisiana Tech University (R Videos and Computer exercise reviewer)
Hisham Foad (Aplia Home work reviewer and Glossary)
Kenneth H. Brown, Missouri State University (R Videos creator)
Scott Kostyshak, University of Florida (R Videos reviewer)
Ujwal Kharel (Test Bank and Adaptive Test Prep)

Data Sets—Available in Six Formats

With more than 100 data sets in six different formats, including Stata®, R, EViews®, Minitab®, Microsoft® Excel, and Text, the instructor has many options for problem sets, examples, and term projects. Because most of the data sets come from actual research, some are very large. Except for partial lists of data sets to illustrate the various data structures, the data sets are not reported in the text. This book is geared to a course where computer work plays an integral role.

Updated Data Sets Handbook

An extensive data description manual is also available online. This manual contains a list of data sources along with suggestions for ways to use the data sets that are not described in the text. This unique handbook, created by author Jeffrey M. Wooldridge, lists the source of all data sets for quick reference and how each might be used. Because the data book contains page numbers, it is easy to see how the author used the data in the text. Students may want to view the descriptions of each data set and it can help guide instructors in generating new homework exercises, exam problems, or term projects. The author also provides suggestions on improving the data sets in this detailed resource that is available on the book's companion website at http://login.cengage.com and students can access it free at www.cengage.com.

Instructor's Manual with Solutions

REVISED INSTRUCTOR'S MANUAL WITH SOLUTIONS SAVES TIME IN PREPARATION AND GRADING. The online Instructor's Manual with solutions contains answers to all exercises in this edition. Teaching tips provide suggestions for presenting each chapter's material. The Instructor's Manual also contains sources for each of the data files with suggestions for using the data to develop problem sets, exams, and term papers. The Instructor's Manual is password-protected and available for download on the book's companion website.

Test Bank

Cengage Testing, powered by Cognero® is a flexible, online system that allows you to import, edit, and manipulate content from the text's test bank or elsewhere, including your own favorite test questions; create multiple test versions in an instant; and deliver tests from your LMS, your classroom, or wherever you want.

PowerPoint Slides

UPDATED POWERPOINT® SLIDES BRING LECTURES TO LIFE WHILE VISUALLY CLARIFYING CONCEPTS. Exceptional PowerPoint® presentation slides, created specifically for this edition, help you create engaging, memorable lectures. The slides are particularly useful for clarifying advanced topics in Part 3. You can modify or customize the slides for your specific course. PowerPoint® slides are available for convenient download on the instructor-only, password-protected section of the book's companion website.

Scientific Word Slides

UPDATED SCIENTIFIC WORD® SLIDES REINFORCE TEXT CONCEPTS AND LECTURE PRESENTATIONS. Created by the text author, this edition's Scientific Word® slides reinforce the book's presentation slides while highlighting the benefits of Scientific Word®, the application created by MacKichan software, Inc. for specifically composing mathematical, scientific and technical documents using LaTeX typesetting. These slides are based on the author's actual lectures and are available for convenient download on the password-protected section of the book's companion website.

Student Supplements

Student Solutions Manual

Now your student's can maximize their study time and further their course success with this dynamic online resource. This helpful Solutions Manual includes detailed steps and solutions to odd-numbered problems as well as computer exercises in the text. This supplement is available as a free resource at www.cengagebrain.com.

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Some of the changes I discussed earlier were driven by comments I received from people on this list, and I continue to mull over other specific suggestions made by one or more reviewers.

Many students and teaching assistants, too numerous to list, have caught mistakes in earlier editions or have suggested rewording some paragraphs. I am grateful to them.

As always, it was a pleasure working with the team at Cengage Learning. Michael Parthenakis, my longtime Product Manager, has learned very well how to guide me with a firm yet gentle hand. Anita Verma and Ethan Crist quickly mastered the difficult challenges of being the content and subject matter expert team of a dense, technical textbook. Their careful reading of the manuscript and fine eye for detail have improved this seventh edition considerably.

This book is dedicated to my family: Leslie, Edmund, and R.G.

Jeffrey M. Wooldridge

About the Author

Jeffrey M. Wooldridge is University Distinguished Professor of Economics at Michigan State University, where he has taught since 1991. From 1986 to 1991, he was an assistant professor of economics at the Massachusetts Institute of Technology. He received his bachelor of arts, with majors in computer science and economics, from the University of California, Berkeley, in 1982, and received his doctorate in economics in 1986 from the University of California, San Diego. He has published more than 60 articles in internationally recognized journals, as well as several book chapters. He is also the author of *Econometric Analysis of Cross Section and Panel Data*, second edition. His awards include an Alfred P. Sloan Research Fellowship, the Plura Scripsit award from *Econometric Theory*, the Sir Richard Stone prize from the *Journal of Applied Econometrics*, and three graduate teacher-of-the-year awards from MIT. He is a fellow of the Econometric Society and of the *Journal of Econometrics*. He is past editor of the *Journal of Business and Economic Statistics*, and past econometrics coeditor of *Economics Letters*. He has served on the editorial boards of *Econometric Theory*, the *Journal of Economic Literature*, the *Journal of Econometrics*, the *Review of Economics and Statistics*, and the *Stata Journal*. He has also acted as an occasional econometrics consultant for Arthur Andersen, Charles River Associates, the Washington State Institute for Public Policy, Stratus Consulting, and Industrial Economics, Incorporated.

Brief Contents

Contents