Introduction to Bayesian Econometrics

Second Edition

This textbook, now in its second edition, is an introduction to econometrics from the Bayesian viewpoint. It begins with an explanation of the basic ideas of subjective probability and shows how subjective probabilities must obey the usual rules of probability to ensure coherency. The book then turns to the definitions of the likelihood function, prior distributions, and posterior distributions. It explains how posterior distributions are the basis for inference and explores their basic properties. The Bernoulli distribution is used as a simple example. Various methods of specifying prior distributions are considered, with special emphasis on subject-matter considerations and exchangeability. The regression model is examined to show how analytical methods may fail in the derivation of marginal posterior distributions, which leads to an explanation of classical and Markov chain Monte Carlo (MCMC) methods of simulation. The latter is preceded by a brief introduction to Markov chains. The remainder of the book is concerned with applications of the theory to important models that are used in economics, political science, biostatistics, and other applied fields. New to the second edition is a chapter on semiparametric regression and new sections on the ordinal probit, item response, factor analysis, ARCH-GARCH, and stochastic volatility models. The new edition also emphasizes the R programming language, which has become the most widely used environment for Bayesian statistics.

Edward Greenberg is Professor Emeritus of Economics at Washington University, St. Louis, where he served as a Full Professor on the faculty from 1969 to 2005. Professor Greenberg also taught at the University of Wisconsin, Madison, and has been a Visiting Professor at the University of Warwick (UK), Technion University (Israel), and the University of Bergamo (Italy). A former holder of a Ford Foundation Faculty Fellowship, Greenberg is the author of the first edition of *Introduction to Bayesian Econometrics* (Cambridge University Press, 2008) and the co-author of four books: *Wages*, *Regime Switching*, and *Cycles* (1992); *The Labor Market and Business Cycle Theories* (1989); *Advanced Econometrics* (1983, revised 1991); and *Regulation, Market Prices, and Process Innovation* (1979). His published research has appeared in leading journals such as the *American Economic Review, Econometrica, Journal of Econometrics, Journal of the American Statistical Association, Biometrika*, and the *Journal of Economic Behavior and Organization*. Professor Greenberg's current research interests include dynamic macroeconomics as well as Bayesian econometrics.

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Contents

List of Figures

List of Tables

Preface to the Second Edition

THE MOTIVATION FOR this edition is the same as for the first: to provide a concise introduction to the main ideas of Bayesian statistics and econometrics. The changes, however, have made the book somewhat less concise. In particular, I have added a chapter on Bayesian nonparametrics and new sections on the ordinal probit model, item response models, factor analysis models, and time-varying variances. I believe that these additional materials make the book more useful to readers. Another difference is that this edition adopts the R statistics environment as the primary tool for computing.

In addition to those thanked in the preface to the first edition, without implicating them in any errors or omissions, I offer my sincere gratitude to John Burkett, Stephen Haptonstahl, Alejandro Jara, Kyu Ho Kang, Xun Pang, Jong Hee Park, Srikanth Ramamurthy, Richard Startz, and Ghislain Vieilledent.

I am grateful for the continued support of Lisa, Aida, my grandchildren, and Sylvia Silver and her family.

With sadness, I note the recent passing of my friends and colleagues Peter Steiner, Arthur Goldberger, and Arnold Zellner, and of my dear son Arthur, to whom I dedicate this edition.

Preface to the First Edition

To Instructors and Students

THIS BOOK IS a concise introduction to Bayesian statistics and econometrics. It can be used as a supplement to a frequentist course by instructors who wish to introduce the Bayesian viewpoint or as a text in a course on Bayesian econometrics supplemented by readings in the current literature.

While the student should have had some exposure to standard probability theory and statistics, the book does not make extensive use of statistical theory. Indeed, because of its reliance on simulation techniques, it requires less background in statistics and probability than most books that take a frequentist approach. It is, however, strongly recommended that the student become familiar with the forms and properties of the standard probability distributions collected in Appendix A.

Since the advent of Markov chain Monte Carlo (MCMC) methods in the early 1990s, Bayesian methods have been extended to a large and growing number of applications. This book limits itself to explaining in detail a few important applications. Its main goal is to provide examples of MCMC algorithms to enable students and researchers to design algorithms for the models that arise in their own research. More attention is paid to the design of algorithms for the models than to the specification and interpretation of the models themselves because I assume that the student has been exposed to these models in other statistics and econometrics classes.

The decision to keep the book short has also meant that I have taken a stand on some controversial issues rather than discussing a large number of alternative methods. In some cases, alternative approaches are discussed in end-of-chapter notes.

Exercises have been included at the end of chapters, but the best way to learn the material is for students to apply the ideas to empirical applications of their choice. Accordingly, even though it is not explicitly stated, the first exercise at the end of every chapter in Part III should direct students to formulate a model, collect

data, specify a prior distribution on the basis of previous research, design and, if necessary, program an algorithm, then present the results.

A link to the Web site for the course may be found at http://edg.wustl.edu/. The site contains errata, links to data sources, some computer code, and other information.

Acknowledgments

I would like to acknowledge and offer my sincere gratitude to some of the people who have helped me over my career. On the professional side, I start with my undergraduate years at the business school of New York University, where Abraham Gitlow awakened my interest in economics. My first statistics course was with F. J. Viser and my second with Ernest Kurnow, who encouraged me to continue my studies and guided me in the process.

At the University of Wisconsin, Madison, I was mentored by, among others, Peter Steiner and Guy Orcutt. Econometrics was taught by Jack Johnston, who was writing the first edition of his pathbreaking book, and I was fortunate to have Arthur Goldberger and Arnold Zellner as teachers and colleagues. My first mathematical statistics course was with Enders Robinson, and I later audited George Box's class, where I received my first exposure to Bayesian ideas. Soon afterward, Zellner began to apply the methods to econometrics in a workshop that I attended.

My interest in Bayesian methods was deepened at Washington University first by E. T. Jaynes and then by Siddhartha Chib. Sid Chib has been my teacher, collaborator, and friend for the last fifteen years. His contributions to Bayesian statistics, econometrics, and MCMC methods have had enormous impact. I have been extremely fortunate to have had the opportunity to work with him. The students in my courses in Bayesian econometrics contributed to my understanding of the material by their blank stares and penetrating questions. I am most grateful to them.

My colleagues and the staff of the Economics Department at Washington University have always been extremely helpful to me. I am delighted to thank them for their support.

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On the personal side, I thank Arthur and Aida, Lisa and Howard, my grandchildren, and my colleagues and friends, particularly Sylvia Silver, Karen Rensing, Ingrid and Wilhelm Neuefeind, Maureen Regan and Sid Chib, Jasmine and Steve Fazzari, and Camilla and Piero Ferri.

In December 2005 my wife of more than 46 years passed away. I dedicate this book to Joan's memory.