1 Introduction

There is currently little agreement among macroeconomists about the structure of the economy. The recent popularity of the assumption of rational expectations has, for example, led to the construction of a number of new econometric models that differ considerably from previous models. Even among models without rational expectations, there are considerable differences in the specification of many equations, as any casual glance at them will reveal. This lack of agreement also manifests itself in quite different monetary and fiscal policy recommendations that are generally made at any one time by different economists.

At the beginning of large-scale model construction in the early 1950s, one might have thought that there would be a gradual and fairly systematic improvement in the accuracy of the specification of the equations, so that by the early 1980s there would exist a generally agreed upon model. Obviously this is not the case, and in fact there has been a movement in the last decade among people doing macroeconomic research away from large-scale models to much smaller ones. Also, as the large-scale models have become commercially successful, interest among the model practitioners in what one would call scientific research has waned. Estimation and analysis of these models are computationally expensive, and the commercial payoff from extensive testing and analysis of them is not likely to be very large, given that the models are subjectively adjusted before being used.

My research has been concerned with large-scale models and is thus contrary to the general trend of the last decade. The implicit premise on which this work is based is that a few equations are not sufficient to give a good approximation of the structure of the economy. Part of this book is a summary of this work and an attempt to stimulate more people to move into the field.

I have had three goals in writing this book. The first is to provide a reference book for advanced graduate students on the tools needed to construct and analyze macro models. Estimation techniques are discussed in Chapter 6. The emphasis in this chapter is on nonlinear methods, since most macroeconometric models are nonlinear, and on computational problems.

Chapters 7 – 11 are concerned with techniques that are used to analyze models once they have been estimated. Chapter 7 discusses deterministic and stochastic simulation techniques that are used to solve models. The evaluation of predictive accuracy is discussed in Chapter 8, and Chapter 9 covers the evaluation of static and dynamic properties. Optimal control techniques are considered in Chapter 10. Chapter 11 discusses the special techniques that are needed for the estimation and analysis of rational expectations models. Tools are also considered to some extent in Chapter 2, which is concerned with the methodology of macroeconomics. In particular, the transition from theoretical to econometric models is discussed in this chapter. In a loose sense this transition can be considered to be a "tool" of the trade, although it is seldom discussed.

The second goal is to present my current macroeconometric model, both the theory behind it and the actual equations. The theoretical basis of the model is discussed in Chapter 3, and the econometric model is presented in Chapter 4. The data for the model are discussed in Appendixes A and B. The model is used in Chapters 6 – 11 to illustrate the various techniques. After a technique is explained, it is applied to the model. This procedure helps in understanding the techniques and provides information on the computational costs of each technique.

The second goal is a complement to the first in that it provides the student with an actual example of the specification, estimation, and analysis of a model. This may be particularly helpful in understanding topics such as the transition from theoretical to econometric models. This knowledge is more easily conveyed by means of examples than it is by discussion in the abstract. It should be stressed, however, that the model presented in this book is not meant solely for illustration; it is not a "textbook" model in the sense of being deliberately simplified for expository purposes. The model is the actual model that I am working on, and it is currently my best attempt at approximating the structure of the economy.

The third goal is to argue, partly by way of example, for a particular methodology. This is dangerous business, and I hasten to add that I do not mean to be particularly rigid on this matter. The world of scientific discourse is at times chaotic, and it is probably not sensible to try to characterize this world as one with a single methodology. Nevertheless, it seems to me that macroeconomics has suffered in the past from too few attempts to test alternative theories, and the methodology that is discussed in this book stresses the testing of theories in a particular way.

Testing alternative theories or models in macroeconomics is difficult. It is

relatively easy with aggregate time series data to fit the data well within the sample period, and thus a good within-sample fit is no guarantee that the particular equation or model is a good representation of the actual process generating the data. It is also difficult to make comparisons of predictive accuracy across models because of differences in the number and types of variables that are taken to be exogenous. The existence of these problems is undoubtedly one of the main reasons there has been so little progress in narrowing the disagreements within macroeconomics. I have, however, recently proposed a method for comparing alternative models that does take account of these problems, and the methodological approach of this book centers around the use of this method.

The method is discussed in detail in Chapter 8, but it will be useful to give a brief outline of it here. The method estimates variances of prediction errors, and in doing so it accounts for the four main sources of uncertainty of a prediction: uncertainty due to (1) the error terms, (2) the coefficient estimates, (3) the exogenous variable predictions, and (4) the possible misspecification of the model. Because the method accounts for all four sources, it can be used to make comparisons across models. The method, in other words, puts each model on an equal footing and thus allows comparisons to be made. Of particular importance is the accounting for the possible misspecification of the model. By doing this, the method has the potential for weeding out models that fit the data well within sample, but are in fact poor approximations of the structure.

The major methodological theme of this book is that one should be able in the long run to use the method to weed out inferior specifications and to begin to narrow the range of disagreements in macroeconomics. By "long run" in this case is meant more than, say, the next five or ten years. Much work remains to be done on the specification of different theoretically based econometric models, and the method itself requires some time to learn to use. It is also possible that better methods will be developed in the future for making comparisons. At any rate, it seems too early to draw strong conclusions regarding which model best approximates the structure, and no such conclusions have been made in this book. The method has been used in this book to compare my US model to four other models: an autoregressive model, two vector autoregressive models, and a twelve-equation linear model. (These four models are presented in Chapter 5.) Although the results of these comparisons, which are discussed in Chapter 8, may be useful reference material for others, many more comparisons with other models are needed before one can draw any strong conclusions about my model.

It will be obvious in what follows that this "wait and see" theme plays an important role in this book. Whenever a theory or approach is discussed that is different from mine, a statement is made to the effect that the differences can be tested in the long run. A computer program is available for carrying out the tests (that is, for using the method to compare alternative models), and I hope that this book will stimulate work of this kind.

It is important to note that the method tests econometric models, not theoretical models. Another important methodological question, which is also considered in this book, is what the results of testing econometric models have to say about theoretical models. Given that the transition from theoretical to econometric models is usually not very tight in macroeconomics, the question remains after, say, a particular econometric model has been chosen to be the best approximation of the structure what the results say about the theory on which the econometric model is based. Does this mean, for example, that the theory is "confirmed?" This issue is discussed in Section 2.3.

There are many computational problems involved in dealing with large-scale nonlinear models, and this may be one reason that research on these models has declined in recent years. Many of these problems are, however, much less serious now than they were a few years ago, and I have tried to indicate in the text, primarily by way of example, the computational costs of each technique. A computer program has been written that handles all the techniques discussed in this book. An outline of the logic of this program is presented in Appendix C, and the program is available for distribution. It has the advantage that once a model has been set up in the program, all the techniques can be applied to it with no further programming. For the more advanced techniques, this can represent a considerable saving in research time.

This book is not a survey of the field and is not a textbook in the usual meaning of this word. The subject matter spans many areas—methodology, macroeconomic theory, specification of econometric models, estimation techniques, other econometric techniques, optimal control issues, rational expectations models, computational issues—and it is not my intention to provide a textbook treatment of each area. I have instead selected and discussed those topics within an area that I think are important for macroeconometric work. This approach is by nature idiosyncratic. I make no apologies for this, since I do not mean this to be the usual kind of textbook, but the reader should be warned what not to expect.

1.1 Guide to the Book

A subset of this book is a book on my United States (US) model, and another subset is a book on my multicountry (MC) model. They are located in the following sections:

US Model
- Theory: Section 3.1
- Specification and Estimation: Section 4.1
- Further Estimation: Sections 6.5 and 6.6
- Testing and Analysis: Sections 7.5.1, 8.5, 9.4, 10.4, and 11.7
- List of Equations: Sections 4.1.4 through 4.1.9 and Appendix A

MC Model (other than the US Model)
- Theory: Section 3.2
- Specification and Estimation: Section 4.2
- Testing and Analysis: Sections 7.5.2, 8.6, and 9.5
- List of Equations: Tables 4-1 through 4-13 and Appendix B

Sections 9.4 and 9.5 are of particular importance in understanding the properties of the models.

If one is interested only in the US or the MC model, the rest of the book can be omitted. The cost of doing this is that none of the techniques that are applied to the models will have been explained. If, on the other hand, the reader is interested only in the techniques, the sections listed above can be omitted. The cost of doing this is that no applications of the techniques will have been discussed. In particular, one loses from this latter approach an example of the transition from a theoretical to an econometric model, which is a tool that is best described by means of examples.

Chapter 7 on the solution of models is a prerequisite for Chapters 8–11. The discussion of the FIML estimation technique in Chapter 6 is required for the discussion of the estimation of rational expectations models in Chapter 11. The discussion of the various models in Chapter 5 is required for some of the applications. Otherwise the individual chapters are self-contained.

1.2 Conventions Adopted

The number of symbols used in Chapters 3 and 4 is fairly large, and for ease of reference the symbols have been listed in alphabetical order in tables. The symbols for the variables in the theoretical model in Chapter 3 are listed in Table 3-1, and the symbols for the variables in the econometric model in

Chapter 4 are listed in Table A-4 of Appendix A and in Table B-2 of Appendix B. Table A-4 presents the variables for the United States, and Table B-2 presents the variables for the other countries. The variables used for the econometric models in Chapter 5 are also used for the econometric model in Chapter 4, and thus Tables A-4 and B-2 are also relevant for Chapter 5.

I have tried to keep the notation simple. One or two letters usually denote a variable, and subscripts have generally been used only when the reference would otherwise be ambiguous. For example, there are three housing investment variables in the US model in Chapter 4, one each for the household, firm, and financial sectors, and therefore subscripts h, f, and b have been used for the housing investment variable IH. There is, however, only one housing stock variable (denoted KH), and although this variable pertains to the household sector, no subscript h has been used for it. A t subscript has been used for the variables in Chapter 3 to denote the period in question, but, with a few exceptions, this has not been done for the variables in Chapter 4. Some confusion might have resulted had the subscript not been used for the theoretical model because of the multiperiod nature of the maximization problems; no confusion is likely to result from not using the t subscript for the econometric model.

A coefficient estimate will be said to be "significant" if its absolute value is greater than or equal to twice the size of its estimated standard error. An explanatory variable will be said to be significant if its coefficient estimate is significant. Although this convention facilitates the discussion of results, no precise statistical statement is implied by its use. Given the searching for equations with good statistical properties that is done in macroeconometric work, classical statistical tests are not applicable. In practice these tests are generally not used in a rigorous way to decide on the final specification of a model.

By "t-statistic" in this book is meant the absolute value of a coefficient estimate divided by its estimated standard error. In other words, the minus sign has been dropped from what is conventionally referred to as the t-statistic. This should cause no confusion, and it makes the results somewhat easier to present.

Unless otherwise stated in the text, none of the goodness of fit measures have been adjusted for degrees of freedom. For example, in computing the standard error of an estimated equation, the sum of squared residuals has been divided by the number of observations, not the number of observations minus the number of coefficients estimated. For the general model considered

in this book (nonlinear, simultaneous, dynamic), only asymptotic results are available, and so if any adjustments were made, they would have to be based on analogies to simpler models. In many cases there are no obvious analogies, and it seemed best simply to forgo any adjustments. Fortunately, in most cases the number of observations is fairly large relative to numbers that might be used in the subtraction, and therefore the results are not likely to be sensitive to the present treatment.

The phrase "rational expectations" is used in this book in the sense of Muth (1961). An expectation of a variable is said to be "rational" if, given a set of exogenous variable predictions, it is what the model predicts the variable to be. This definition requires that there be a model and a set of exogenous variable predictions. In practice an expectation is sometimes said to be rational if "all available information" has been used in forming it. The problem with this definition is that it is vague concerning what "all available information" means, and so I have not used it. In the Muth sense it is clear what this means, "all available information" means using the model (including all the nonlinear restrictions involved in going from the structural coefficients to the reduced form coefficients) to solve for the expectation.

In discussing the properties of a model, I have used statements to the effect that a change in variable A "leads to" or "results in" a change in variable B, where both variables A and B are endogenous. In a simultaneous equations model, which is what most of the models considered in this book are, the use of statements like this is not precise, since in general every endogenous variable affects every other one. This way of discussing the results is, however, helpful in explaining the properties of a model, and as long as one is aware of its loose nature, no confusion should result. On a related matter, I have referred to the "matching" of variables to equations when discussing the solution of a model. This is again only for pedagogical purposes, since in general every equation influences the determination of every variable in a simultaneous equations model.

1.3 Computer Work

This book went through two main drafts. For the first draft nearly all the computer work was done on a VAX 11/780 at Boston College. For the second draft all the econometric models were updated and the computer work was done over on an IBM 4341 at Yale University. Only the updated results are presented in this book, but whenever possible, both the VAX times for the old

results and the IBM times for the new results are presented. The computer times that are presented, especially the IBM times, are fairly rough. Sometimes more than one set of results was obtained in a single job, and some sets of results required parts of many jobs. It was not always easy to keep track of exactly how much computer time each task took. This was particularly true on the IBM, which did not allow elapsed times to be computed within a single job. Also, the basic sample period used for the IBM work was slightly larger than that used for the VAX work (115 versus 107 observations), and this adds to the imprecision of the comparisons of the estimation jobs. Nevertheless, the times reported here are not likely to be off by more than about 25 percent, which is adequate for giving a general idea of the computational costs of each technique. Relative to the IBM, the VAX is faster at reading from and writing to the disk than it is at numerical computations. The VAX times would thus not be a constant proportion of the IBM times even without measurement error; the relative speeds vary depending, among other things, on the amount of reading and writing that is done.

To give an indication of the likely times on faster computers, the IBM 4341 is about five times slower than the IBM 3033, which in turn is about four times slower than one of the fastest computers currently available, the CRAY-1. The times reported in this book for the IBM 4341 are thus likely to be about twenty times less for a CRAY-1. This comparison is, however, very rough, and it could be off by a factor of 2 or more. The relative speeds of computers vary considerably depending on the type of job. Moreover, the time for the same job on the same type of computer can vary across installations depending on the other features of the installations. To give an example, near the end of the computer work for the first draft of this book, Boston College installed a second VAX 11/780, which I began using. This VAX seemed to be roughly twice as fast as the other one. There are undoubtedly subtle reasons for this difference, but the main point here is that any comparison of time between computers is very rough unless one has actually run the job on both computers. All the VAX times reported in this book are for the first (slower) VAX. Some of the computer work for the results in Chapter 11 was done on an IBM 360/91 at Columbia University. This machine is about 2.5 times faster than an IBM 4341.

It seems clear that time is on our side with respect to computer costs. It is likely that in, say, ten years, computer costs for results like those in this book will be trivial. At the same time, many of the problems that it was not feasible to solve for this book should become soluble.

1.4 References

Although part of this book is a summary of my previous work, the present volume is self-contained in that it does not require that any of the earlier literature have been read. I have indicated in a note to each chapter (given at the end of the book) the references to my prior research that the chapter draws upon, but otherwise little mention of these references is made. This is not true, however, of references to other authors, which are scattered in the usual way throughout the chapters.