MACROECONOMIC THEORY
SECOND EDITION

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PREFACE TO THE SECOND EDITION

This is a revision of a book that was first published in 1979. In addition to some minor corrections and additions occurring throughout the text, the major changes consist in the deletion of one chapter of the old edition, the addition of three entirely new chapters, and substantial additions to three of the original chapters (those on difference equations, on stochastic difference equations, and on investment under uncertainty). I have also added an introductory section containing personal remarks about the history of some of the ideas in this book.

When the manuscript for the first edition of this book was sent to the publisher in 1977, I was only beginning to understand the ramifications of the cross-equation restrictions that the hypothesis of rational expectations imposes on an equilibrium stochastic process of a dynamic model. Some of those ramifications had leaked into the first edition of this book, but many more are present in this edition. A formula expressing these restrictions in linear models was published by Lars Hansen and me in 1980. That formula is applied repeatedly in this edition.

The first edition appeared at a time when discussions of the "policy ineffectiveness proposition" occupied much of the attention of macroeconomists. As work of John B. Taylor has made clear, the methodological and computational implications of the hypothesis of rational expectations for the theory of optimal macroeconomic policy far transcend the question of whether we accept or reject particular models embodying particular neutrality propositions. Indeed, relative to the simple early models of Barro and Sargent and Wallace, models in which government policy choices affect allocations require much more intricate exploitation of the cross-equation restrictions of rational expectations in optimally choosing government policy. The current edition contains many more examples of models in which a government faces a nontrivial policy choice than did the earlier edition.

I have completely rewritten the chapter on consumption and have added a new chapter on government debt and taxes, which analyzes the Barro tax-smoothing model, and a new chapter on dynamic optimal taxation, which analyzes the time inconsistency problem. I have also extended the treatment of both nonstochastic and stochastic linear difference equations. Applications of stochastic linear difference equations have become increasingly common in macroeconomics since the first edition appeared, with vector autoregressions and rational expectations econometrics becoming widespread. I have also added substantially to the chapter on investment under uncertainty.

I received helpful comments and criticisms on this material from many people. I would especially like to thank Charles Whiteman, Richard Todd, Shinichi Watanabe, Lawrence Christiano, Rao Aiyagari, Randall Wright, Richard Rogerson, Albert Marcet, Rodolfo Manuelli, Michael Stutzer, Will Roberds, and Eugene Yun for their comments. Wendy Williamson provided excellent research assistance and typing help, as well as discipline in meeting deadlines. For help in preparing graphs, I would like to thank Susan Mendesh, Steven Morus, George McCandless, and Robert Litterman. I would like to thank once more the Federal Reserve Bank of Minneapolis and the University of Minnesota for providing me with a wonderful environment for studying macroeconomics.

Christopher A. Sims and Neil Wallace taught me much of what is contained in this book.

July 1986

PREFACE TO THE FIRST EDITION

This book grew out of a series of lecture notes prepared for a first-year graduate course at the University of Minnesota. Part I is devoted to a presentation of some fairly standard nonstochastic macroeconomic analysis. Part II attempts to provide an introduction to some of the methods and issues in stochastic macroeconomics. This book does not purport to present a unified treatment of a single, widely received macroeconomic theory since the economics profession has not yet attached itself to any one such theory. On the contrary, one can concoct a large variety of plausible macroeconomic models at the level of rigor of the usual Keynesian model, models exhibiting very different responses to policy experiments. A partial aim of the first five chapters and the exercises given there is to exhibit the extent of this variety.

Part II uses a somewhat roundabout means of production and devotes some space to a treatment of some of the tools of modern macroeconomics: lag operators, linear least squares prediction, and stochastic difference equations. The chapter on stochastic difference equations is intended for browsing on the first reading, only parts of this chapter being required for understanding the sequel.

I received helpful comments from Thomas Doan, Preston Miller, Arthur Rolnick, Gary Skoog, Dale Henderson, Charles Whiteman, Rusdu Saracoglu, Neil Wallace, Mathew Canzoneri, and George McCandless. Special thanks are due to George McCandless who proofread and criticized the manuscript and prepared the Index.

I would like to thank the Research Department of the Federal Reserve Bank of Minneapolis for the support of my research and for permitting me to serve as an advisor for the past seven years. The Bank has provided an ideal environment for thinking about macroeconomics. Needless to say, the Federal Reserve Bank is not responsible for any of the opinions expressed in this work. Finally, I would like to thank the staff of Academic Press for their editorial assistance.

"A fellow may do many a crazy thing, and as long as he has no theory about it, we forgive him. But if there happens to be a theory behind his actions, everybody is down on him."

Gene Henderson, in *Henderson the Rain King* by Saul Bellow.

INTRODUCTION TO THE SECOND EDITION

This book was written gradually and continuously over the years 1970 to 1985. It amounts to a record of notes on lectures that I gave during those years in the graduate course in macroeconomic theory at the University of Minnesota. During those years there occurred revolutionary changes in the subject of macroeconomics. The fact that this book was written over a period of time that spanned this "rational expectations revolution" is evident from the book's structure.

The first five chapters, which I taught from 1970 to about 1974, describe the static analysis of various classical and Keynesian macroeconomic models. These chapters were written at a time when I was a devoted user of Keynesian economics and were heavily influenced by my studies of Tobin's work and his insistence on careful treatments of time and of stocks and flows. I was also very much influenced by papers by and discussions with my colleague Neil Wallace, who in those days was studying the foundations of Keynesian models. Two aspects of the looming rational expectations revolution are foreshadowed in these early chapters. First, following the ideas of Tobin and Wallace, these chapters stressed the important technical role played in these static analyses by the assumption that expectations of inflation are exogenous. It is that assumption that makes a static, or point-in-time, analysis capable of determining equilibrium values of all of the endogenous variables that have to be determined. Technically that assumption prevents the models from becoming dynamic ones in the forms of differential equations. Second, these early chapters contained an attempt to find "the people" underneath the schedules and to tell stories about the ends that their decisions were imagined to be serving. The stories in these chapters are not satisfactory by today's standards, for they are not fully coherent and cannot be made so by simple modifications. But it was thinking hard about precisely these models, about the hypothetical people in them and their objectives, and about the role of exogenous price expectations which led Neil

Wallace and me toward rational expectations macroeconomics. It is true that there were other, more elegant routes toward that end, through general equilibrium theory or optimal growth theory, but those were not the routes that Wallace and I took. (While Neil Wallace and I were struggling with Keynesian models, Robert E. Lucas, Jr., and Edward C. Prescott were mostly traveling along these alternative and more direct routes.) I preserve these first five chapters partly out of a desire not to obliterate or smooth out the trail which took me from Keynesian economics into rational expectations. Furthermore, it remains useful to study these models in their own right, both because a large part of the economics profession still has faith in them, and because they provide a concise introduction to some of the classic issues of the subject.

Keynesian and classical models of the type studied in the first five chapters consisted of collections of decision rules which were assumed to be fixed in the face of various policy interventions. By a decision rule is meant a function expressing an agent's decision about something as a function of the pertinent information that he possesses at the time he makes the decision. The consumption function, investment function, and demand schedule for money are all examples of decision rules in the Keynesian model. In Keynesian economics, policy experiments were conducted by holding these decision rules fixed while varying settings for government expenditures, taxes, and the money supply. Sometimes the adjective "structural" is used to denote the property of being invariant with respect to the class of policy interventions to be analyzed. Keynesian models treated decision rules as structural.

It turned out that thinking both about the exogeneity of expectations of inflation and about the purposes for which the hypothetical people in the model were making decisions undermined the notion that decision rules could be regarded as structural. Since expectations of inflation played an important role in these models, for example in analyses of the "Fisher effect," it was natural to seek to close the model by making them endogenous. Since the models were not random, and since they could be used to determine the path of future prices and thus actual inflation, essentially by repeating a static analysis for each successive point in time, it was also natural to impose that expected inflation equals actual inflation. In a perfectly certain environment, "perfect foresight" seems to be the most reasonable assumption. While this was a natural step, it was not an easy one to take or to see fully the consequences of. Chapter I already wrestles with this issue and indicates what Wallace and I perceived the difficulties to be in carrying out such an analysis, as of 1971 or so. Imposing perfect foresight on price expectations had the effect of converting a static model into a dynamic one which had to be analyzed using the tools of differential equations. Furthermore, the simple step of imposing perfect foresight meant that, expressed as functions of variables dated t and earlier, decision rules are not structural; with foresight, such decision rules would depend implicitly on the time paths or rules for setting paths of future government policy variables. This dependence would show up by making decision rules expressed as functions of variables dated t and earlier themselves functions of the rules or laws of motion imagined to govern the government policy variables. This theoretical observation is the basis for "Lucas's critique" stating that the decision rules of Keynesian models are not structural in the sense of being invariant with respect to changes in the time paths for government policy variables. This theoretical observation destroyed the scientific grounds for believing the policy conclusions drawn from Keynesian models. It also created a challenge to find methods for studying macroeconomic decision rules which respond systematically and predictably to the government's choice of strategy or time path for its policy variables. The remaining chapters of this book are devoted to describing such methods and a variety of sample models that were constructed by using such methods.

These remaining chapters contain a mixture of tools and models. The thoroughness with which methods and models are mixed may strike some readers as yielding a haphazard presentation. Again, this manner of presentation reflects the fact that the book was composed over a number of years, and that my own process of learning the subject has continually mixed technical tools and economic models. In this learning process, the desire to understand a particular economic model or phenomenon often prompted my learning to use some mathematical tool or other. More often than not, once that tool was possessed, it became clear how a further class of economic models or phenomena could be studied. This leap-frogging approach is reflected in this book. In retrospect, it would have been possible to smooth out the presentation of the material by isolating the purely technical material from that with economic content. I purposefully did not do so in order not to conceal what amounts to my own personal record of learning the subject. Also, to me it seems more fun to learn about the tools when applications are quickly mentioned to practice upon.

One example of a theoretical economic issue which required investment in mathematical tools has already been mentioned: the construction of models with foresight about future rates of inflation. The reason that it took Neil Wallace and me so long to understand this matter was that we didn't fully enough understand the structure of difference equations, even linear ones. Chapter IX summarizes much of what we needed to know in order to create models in which agents had foresight about the rate of inflation. However, once the tools of Chapter IX were in hand, other economic problems and the solutions to them readily suggested themselves. Thus, the variety of examples of tractable dynamic models suggested at the end of Chapter IX were easy to understand once the structure of difference equations was understood. This is only one illustration of the fact that as economic analysts we are directed by, if not prisoners of, the mathematical tools that we possess.

As another example of the same point, one of the main substantive economic motivations of my own studies has been to understand the connections between economic theories and econometric tests of those theories. A natural setting for creating an understandable relationship between the two is provided by random difference equations or "stochastic processes." Macroeconomists and applied time series econometricians very often report estimates of random difference equations. My initial goal in learning the material summarized in Chapter XI was to understand the structure of the linear stochastic difference equations that are often, if not usually, estimated in econometric studies. These were also the tools that Slutsky and Frisch had long ago forcefully commended to business cycle theorists. Furthermore, the theories of prediction of Wiener and Kolmogorov and the notions of causality proposed by Wiener, Granger, and Sims seemed potentially relevant for building stochastic models to understand phenomena in which foresight is important. In addition, stochastic difference equations formed the language used by John F. Muth in his two early articles on rational expectations. The material in Chapter XI had to be mastered in order fully to understand Muth's contributions and in order to be able to put his ideas to work in new contexts. This material turned out to provide insights and possess applications in a whole variety of directions of importance to macroeconomics. Key formulas for formulating rational expectations models (e.g., the formula for the expectation of a "geometric distributed lead"), the notion of "vector autoregressions," the structure of "leading indicators," and even the definition of the "business cycle" are among the economic dividends of the material in Chapter XI. It would not be much of an exaggeration to claim that Chapter XI introduces the "language of applied macroeconometrics" or at least one dialect. Furthermore, there turns out to be an intimate relationship between the classical linear prediction theory described in Chapter XI and the classical linear control theory described in Chapter IX.

When mastered, the tools of stochastic difference equations or stochastic processes prompt one to think about time series observations in terms of collections of (sample) moments with a linear structure that can be characterized by projections in various directions. Usually, these moments include the second moments of all pairs of variables under consideration at all leads and lags. This way of thinking affects both the way that we process observations and the way that we conceive "policy questions," whether we are proceeding formally or informally in an armchair. Once one begins to think about data in this way, it is natural to want economic models which produce stochastic difference equations as the outcome of the economic theorizing. It is desirable that these difference equations have free parameters that describe preferences and opportunities. This creates a framework in which the moments of the observable data can potentially be interpreted in terms of the economic parameters describing preferences and opportunities. There are many examples of this approach in this book. One key example is provided by the linear version of the Lucas-Prescott model of investment under uncertainty that is described in Chapter XIV. Linear stochastic difference equations lend themselves to the ready formulation and practical application of such models. In this book, the potential use of this idea is stressed in the context of a variety of versions of Lucas-Prescott models.

In terms of economic policy, thinking of stochastic processes promotes regarding policies as stochastic processes for the variables under the control of the policy maker. Rather than attempting to analyze the effects of one-time actions that are isolated in time, one is prompted to think of policy-making as a process producing a strategy which is to be used repeatedly over time and which results in a stochastic process for the policy maker's instrument of control. This is a good example of an area in which the tools that we are using influence the very questions that we ask and the way that we pose them. Thinking about policy in terms of repeated strategies or rules or regimes is natural for someone who thinks about dynamic economies in terms of stochastic processes.

I offer one more thought on the relationship between tools and models. I have mentioned the "rational expectations revolution," as the collection of developments in dynamic macroeconomics over the last fifteen years is sometimes called. Whether one wishes to refer to these developments as a "revolution" or as an evolution which proceeded continuously and inevitably out of Keynesian macroeconomics seems to be partly a matter of mood or taste. In the United States, macroeconomics since World War II has included a more or less continuous effort to discover microeconomic underpinnings behind the decision rules governing the Keynesian categories of consumption, investment, and money demand. Many of the celebrated contributions to macroeconomics in the post-war period were results of this effort, including the works of Friedman and Modigliani on consumption, Tobin, Baumol, and Samuelson on the demand for money, and Haavelmo, Jorgenson, Treadway, Gould, and Lucas on investment. This work was applauded by the profession in proportion to its sophistication and success in applying optimal control theory for understanding the decision in question. A widely agreed upon ultimate goal of such research was to combine the resulting decision rules obtained from these efforts to create ever more sophisticated Keynesian macroeconometric models. The Brookings Model emerged from an explicit attempt to accomplish just this.

From the viewpoint of this long line of research, exploring the implications of rational expectations was an inevitable step. The very same reasons that convinced economists that it is a good idea to analyze investment, consumption, and portfolio decisions by assuming expected utility maximizing agents who solve rich intertemporal problems, also commended the idea that agents would form their expectations optimally, i.e., "rationally." It is probably merely an intellectual coincidence that expectations about the future were the last domain to which macroeconomists applied the theory of optimizing agents: it just happened that economists in general and macroeconomists in particular learned the tools of optimal control (e.g., calculus of variations) somewhat before they learned the tools of optimal prediction and filtering. (I have already confessed the difficulties that Neil Wallace and I had in seeing how to build rational expectations into the Chapter I and II models, even after we decided that it was a desirable thing to do.)

There was another related strand of research in the Keynesian tradition that led inevitably toward rational expectations. This was the line of work, extending back to Tinbergen, which pursued the idea of applying optimal control theory to macroeconometric models in order to make precise quantitative statements about optimal monetary and fiscal policies. This line of thought, which was pursued by researchers such as Theil, Prescott, and Chow, prompted its advocates to think of a "policy" as a rule or repeated strategy to be chosen by the government to maximize an intertemporal objective function subject to "constraints" which took the form of an econometric model and which played the role of describing the "laws of motion" of the system that the government sought to control. In these policy experiments, the government was imagined to behave precisely as an agent with "rational expectations." In the early applications of this idea, the econometric model, consisting largely of hypothetical decision rules of private agents, was imagined to be fixed with respect to the choice of government policy rule (i.e., the econometric model was credited with being "structural"). In this work, the principle was discovered that the optimal monetary or fiscal policy rule for the government depended on the dynamic constraints faced by the government in the form of an econometric model. That is, it was discovered to be mistaken to expect there to be a single rule for monetary or fiscal policy that would be optimal over a range of alternative economies (econometric models). Technically, this finding was equivalent to the Lucas critique, only the names of the agents being different. It was inevitable that macroeconomists would eventually apply these ideas to private agents' decisions rules as well as those of the government. This would instill symmetry into these policy experiments by assuming that private agents, as well as the government agents, have "rational expectations" or, in other words, that private agents also solve dynamic optimization problems and take into account the constraints that they face, which include the laws of motion for policy variables that are chosen by the government. From the point of view of the evolution of this line of work, it is understandable that many of the earliest advocates and users of rational expectations in macroeconomics were originally Keynesian economists who had been interested in applying control theory for studying optimal monetary and fiscal policies.

The impulse to rational expectations theory was implicit in the agenda of Keynesian macroeconomics all along. However, the idea of rational expectations produced large and discontinuous changes in our conception of macroeconomic equilibria and in our methods for explaining observations. The idea also changed the way we think about optimal macroeconomic policy and about what features we believe a useful quantitative macroeconomic model will eventually have. Even the language that macroeconomists speak has changed. In this sense, there has been a rational expectations revolution.