Stochastic Dynamic Macroeconomics: Theory and Empirical Evidence

Gang Gong
Willi Semmler

OXFORD UNIVERSITY PRESS

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Our present is determined as much by where we want to go as it is by where we have come from.

—Ernst Bloch

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Preface

This book aims to contribute to the study of alternative paradigms in macroeconomics. As with other recent approaches to dynamic macroeconomics, we build on intertemporal economic behavior of economic agents, but stress Keynesian features more than other recent literature in this area. In general, stochastic dynamic macromodels are difficult to solve and to estimate, particularly if intertemporal behavior of economic agents is involved. Thus, besides addressing important macroeconomic issues in a dynamic framework, a major focus of this book is to discuss and apply solutions and estimation methods to models with intertemporal behavior of economic agents.

The material of this book has been presented by the authors at several universities. Chapters of the book have been presented as lectures at Bielefeld University; Foscari University, Venice; the University of Technology, Vienna; the University of Aix-en-Provence; Columbia University, New York; New School University, New York; Bejing University; Tsinghua University, Bejing; the Chinese University of Hong Kong; the City University of Hong Kong; the European Central Bank; and the Deutsche Bundesbank. Some chapters of the book also have been presented at the annual conferences of the American Economic Association, the Society of Computational Economics, and the Society of Nonlinear Dynamics and Econometrics.

We are grateful for comments by the participants at those conferences. We are grateful for discussions with Philippe Aghion, Toichiro Asada, Jean-Paul Bénassy, Peter Flaschel, Buz Brock, Lars Grüne, Richard Day, Ekkehard Ernst, Ray Fair, Stefan Mittnik, James Ramsey, Jens Rubart, Volker Caspari, Malte Sieveking, Michael Woodford, and colleagues at our universities. We thank Uwe Köller for research assistance, and Gaby Windhorst for editing and typing the manuscript. Financial support from the Ministry of Education, Science, and Technology of the State of North Rhine-Westphalia, Germany, and from the Bernhard Schwartz Center of Economic Policy Analysis of the New School University is gratefully acknowledged. Finally, we want to thank anonymous referees and Terry Vaughn of Oxford University Press, who have helped the book to become better.

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Introduction and Overview

The dynamic general equilibrium (DGE) model, in particular its more popular version, the real business cycle (RBC) model, has become a major paradigm in macroeconomics. It has been applied in numerous fields of economics. Its essential features are the assumptions of intertemporal optimizing behavior of economic agents, competitive markets, and price-mediated market clearing through flexible wages and prices. In this type of stochastic dynamic macromodeling, only real shocks, such as technology shocks, monetary and government spending shocks, variations in tax rates, or shifts in preferences generate macro fluctuations.

Recently Keynesian features have been built into the DGE model by preserving its characteristics, such as intertemporally optimizing agents and market clearing, but introducing monopolistic competition and sticky prices and wages. In particular, in numerous papers and in a recent book Woodford (2003) has worked out this new paradigm in macroeconomics, which is now commonly called New Keynesian macroeconomics. In contrast to the traditional Keynesian macromodels, such variants also presume dynamically optimizing agents and market clearing, but sluggish wage and price adjustments.[1]

The standard DGE model fails to replicate essential product, labor market, and asset market characteristics. In our book—different from the DGE model and its competitive or monopolistic variants—we do not presume the clearing of all markets in all periods. As in the monopolistic competition variant of the DGE model, we permit nominal rigidities. Yet, by stressing

Keynesian features in a model with production and capital accumulation, we demonstrate that even with dynamically optimizing agents, not all markets may be cleared.

Solution and Estimation Methods

Whereas models with Keynesian features are worked out and stressed in part III, parts I and II provide the groundwork for them. In parts I and II we build extensively on the basics of stochastic dynamic macroeconomics.

Part I is the technical preparation for the development of our theoretical arguments. Here we provide a variety of technical tools to solve and estimate stochastic dynamic optimization models, which is a prerequisite for a proper empirical assessment of the models we treat. Solution methods are presented in chapters 1 and 2, and estimation methods, along with calibration and the current methods of empirical assessment, are introduced in chapter 3. These methods are applied in the remaining chapters of the book.

Solving stochastic dynamic optimization models has been an important research topic since the mid-1990s, and many different methods have been proposed. Usually an exact and analytical solution of a dynamic decision problem is not attainable. Therefore one has to rely on an approximate solution, which may also have to be computed by numerical methods. Recently, numerous methods have been developed to solve stochastic dynamic decision problems. Among the well-known methods are the perturbation and projection methods (Judd 1998), the parameterized expectations approach (den Haan and Marcet 1990), and the dynamic programming approach (Santos and Vigo-Aguiar 1998; Grüne and Semmler 2004a). When an exact and analytical solution to a dynamic optimization problem is not attainable, one has to use numerical methods. A solution method with higher accuracy often requires more complicated procedures and longer computation time.

In this book, in order to allow for an empirical assessment of stochastic dynamic models, we focus on approximate solutions that are computed from two types of first-order conditions: the Euler equation and the equation derived from the Lagrangian. For these two types of first-order conditions, three types of approximation methods can be found in the literature: the Fair–Taylor method, the log-linear approximation method, and the linear-quadratic approximation method. After a discussion of the various approximation methods, we introduce a method that will be used repeatedly in the subsequent chapters. The method, which has been written into a "GAUSS" procedure, has the advantage of short computation time and easy implementation without sacrificing too much accuracy. We will also compare those approximation methods with the dynamic programming approach.

Often the methods use a smooth approximation of first-order conditions, such as the Euler equation. Sometimes, smooth approximations are not useful if the value function is very steep or if it is not differentiable and thus non-smooth. A method such as that employed by Grüne and Semmler (2004a) can then be used.

Less progress has been made regarding the empirical assessment and estimation of stochastic dynamic models. Given the wide application of stochastic dynamic models expected in the future, we believe that the estimation of such models will become an important research topic. The discussion in chapters 3–6 can be regarded as an important step toward that purpose. Our proposed estimation strategy requires solving the stochastic dynamic optimization model repeatedly, at various possible structural parameters searched by a numerical algorithm within the parameter space. This requires that the solution methods adopted in the estimation strategy should consume as little time as possible while not losing too much accuracy. After comparing different approximation methods, we find the proposed methods of solving stochastic dynamic optimization models, such as those used in chapters 3–6, most useful. We also will explore the impact of the use of different data sets on the calibration and estimation results.

RBC Model as a Benchmark

In part II, we set up a benchmark model, the RBC model, for comparison in terms of either theory or empirics.

The standard RBC model is a representative agent model, but it is constructed on the basis of neoclassical general equilibrium theory. It therefore assumes that all markets (including product, capital, and labor markets) are cleared in all periods, regardless of whether the model refers to the short run or the long run. The imposition of market clearing requires that prices be set at an equilibrium level. At the pure theoretical level, the existence of such general equilibrium prices can be proved under certain assumption. Little, however, has been said about how the general equilibrium can be achieved. In an economy in which both firms and households are price takers, an auctioneer who adjusts the price toward some equilibrium is implicitly presumed to exist. Thus, how an equilibrium is brought about is essentially a Walrasian *tâtonnement* process.

Working with such a framework of competitive general equilibrium is elegant and perhaps a convenient starting point for economic analysis. It nevertheless neglects many restrictions on the behavior of agents: the trading process and the market-clearing process, the implementation of new technology, and the market structure, among many others. In part II, we provide a thorough review of the standard RBC model, the representative stochastic dynamic model of the competitive general equilibrium type. The review starts with laying out a microfoundation, and then discusses a variety of empirical issues, such as the estimation of structural parameters, the data construction, the matching with the empirical data, the asset market implications, and so on. The issues explored in this part of the book provide the incentives to introduce Keynesian features into a stochastic dynamic model as developed in part III. It also provides a reasonable ground on which to judge new model variants by considering whether they can resolve some puzzles, as explored in part II.

Open-Ended Dynamics

One of the restrictions in the standard RBC model is that the firm does not face any additional cost (a cost beyond the usual activities at the current market prices) when it adjusts either price or quantity. For example, changing the price may require the firm to pay a menu cost and also, more important, a reputation cost. It is the cost arising from price and wage adjustments that has become an important focus of New Keynesian research over the last decades.[2] However, there may also be an adjustment cost on the real side arising from a change in quantity. In a production economy, increasing output requires the firm to hire new workers and add new capacity. In a given period of time, a firm may find it increasingly difficult to create additional capacity. This indicates that there will be an adjustment cost in creating capacity (or capital stock, via investment) and, further, that such adjustment cost may also be an increasing function of the size of investment.

In chapter 7, we introduce adjustment costs into the benchmark RBC model. This may bring about multiple equilibria toward which the economy may move. The dynamics are open ended in the sense that the economy can move to a low level or a high level of activity.[3] Such an open-ended dynamics is certainly one of the important feature of Keynesian economics. In recent times such open-ended dynamics have been found in a large number of dynamic models with intertemporal optimization. Those models have been called indeterminacy and multiple equilibria models. Theoretical models of this type are studied in Benhabib and Farmer (1999) and Farmer (1999), and an empirical assessment is given in Schmidt-Grohe (2001). Some of the models are RBC models with increasing returns to scale and/or more general preferences than power utility that generates indeterminacy. Local indeterminacy and a global multiplicity of equilibria can arise here. Other models are monetary macromodels, where consumers' welfare is affected positively by consumption and cash balances, and negatively by the labor effort and an inflation gap from some target rates. For certain substitution properties between consumption and cash holdings, those models admit unstable as well as stable high-level and low-level steady states. There also can be indeterminacy in the sense that any initial condition in the neighborhood of one of the steady states is associated with a path toward, or away from, that steady state (see Benhabib et al. 2001).

Overall, the indeterminacy and multiple equilibria models predict an open-ended dynamics, arising from sunspots, in which the sunspot dynamics are frequently modeled by versions with multiple steady-state equilibria, and there are also pure attractors (repellers), permitting any path in the vicinity of the steady-state equilibria to move back to (away from) the steady-state equilibrium. Although these are important variants of macrodynamic models with optimizing behavior, it has recently been shown that indeterminacy is likely to occur within only a small set of initial conditions.[4] Yet, despite such unsolved problems, the literature on open-ended dynamics has greatly enriched macrodynamic modeling.

Pursuing this line of research, we introduce in chapter 7 a simple model in which one does not need to refer to model variants with externalities (and increasing returns to scale) and/or to more elaborate preferences in order to obtain such results. We show that through the adjustment cost of capital we may obtain non-uniqueness of steady-state equilibria in an otherwise standard dynamic optimization version. Multiple steady-state equilibria, in turn, lead to thresholds separating different domains of attraction of capital stock, consumption, employment, and welfare level. As our solution shows, thresholds are important as separation points below or above which it is advantageous to move to lower or higher levels of capital stock, consumption, employment, and welfare. Our model version thus can explain how the economy becomes history dependent and moves, after a shock or policy influences, to low- or high-level equilibria in employment and output.

Nonclearing Markets

A second important feature of Keynesian macroeconomics concerns the modeling of the labor market. An important characteristic of the DGE model is that it is a market-clearing model. For the labor market, the DGE model predicts an excessive smoothness of labor effort in contrast to empirical data. The low variation in the employment series is a well-known puzzle in the RBC literature.[5] It is related to the specification of the labor market as a cleared market. Although in its structural setting (see, e.g., Stokey et al. 1989) the DGE model specifies both sides of a market, demand and supply, the moments of the macro variables of the economy are generated by a one-sided force due to its assumption on wage and price flexibility; and, thus, on equilibrium in all markets, including output, labor, and capital markets. The labor effort results only from the decision rule of the representative agent to supply labor. In our view, there should be no restriction for the other side of the market, the demand, to have effects on the variation of labor effort.

Attempts have been made to introduce imperfect competition features into the DGE model.[6] In those types of models, producers set the price optimally, according to their expected market demand curve. If one follows a Calvo price-setting scheme, there will be a gap between the optimal price and the existing price. However, it is presumed that the market is still cleared, since the producer is assumed to supply the output according to what the market demands at the existing price. This consideration also holds for the labor market. Here the wage rate is set optimally by the household, according to the expected market demand curve for labor. Once the wage has been set, it is assumed to be rigid (or adjusted slowly). Thus, if the expectation is not fulfilled, there will be a gap between the optimal wage and the existing wage. Yet in the New Keynesian models the market is still assumed to be cleared, since the household is assumed to supply labor regardless of the demand at the given wage rate. (Yet, as we will discuss further in chapter 8, this definition of market clearing is not unambiguous.)

In order to better fit the RBC model's predictions to the labor market data, search and matching theory has been employed to model the labor market in the context of an RBC model. (For further details, see chapter 8.) Informational or institutional search frictions may then explain equilibrium unemployment rates and their rise. Yet, those models still have a hard time explaining the large variation of vacancies and unemployment and the strong shift of unemployment rates, such as those experienced in Europe since the 1980s, as equilibrium unemployment rates.[7]

Concerning the labor market in Keynesian terms, we pursue an approach that allows for a nonclearing labor market. In our view, the decisions with regard to price and quantities can be made separately, both subject to optimal behavior. When the price has been set, and is sticky for a certain period, the price is given to the supplier deciding on the quantities. There is no reason why the firm cannot choose the optimal quantity rather than what the market demands, especially when the optimum quantity is less than the quantity demanded by the market. This consideration will allow for nonclearing markets.[8] Our proposed new model helps to study labor market problems by being based on adaptive optimization in which households, after a first round of optimization, have to reoptimize when facing constraints on supplying labor to the market. On the other hand, firms may face constraints on the product markets. As we will show in chapters 8 and 9, such a multiple-stage optimization model allows for greater volatility of the employment rates compared with the standard RBC model, and also provides, a framework to study the secular rise or fall of unemployment.

Technology and Demand Shocks

A further Keynesian feature of macromodels concerns the role of shocks. In the standard DGE model, technology shocks are the driving force of the business cycles and are assumed to be measured by the Solow residual. Since the Solow residual is computed on the basis of observed output, capital, and employment, it is presumed that all factors are fully utilized. However, there are several reasons to distrust the standard Solow residual as a measure of technology shock. First, Mankiw (1989) and Summers (1986) have argued that such a measure often leads to excessive volatility in productivity, and even the possibility of technological regress, both of which seem to be empirically implausible. Second, it has been shown that the Solow residual can be expressed by some exogenous variables—for example, demand shocks arising from military spending (Hall 1988) and changed monetary aggregates (Evans 1992)—that are unlikely to be related to factor productivity. Third, the standard Solow residual can be contaminated if the cyclical variations in factor utilization are significant.

Since the Solow residual cannot be trusted as a measure of technology shock, researchers have developed different methods to measure technology shocks correctly. All these methods are focused on the computation of factor utilization. There are basically three strategies. The first is to use an observed indicator as proxy for unobserved utilization. A typical example is to employ electricity use as a proxy for capacity utilization (see Burnside et al. 1996). Another strategy is to construct an economic model so that one can compute the factor utilization from the observed variables (see Basu and Kimball 1997; Basu et al. 1998). A third strategy uses an appropriate restriction in a VAR estimate to identify a technology shock (see Gali 1999; Francis and Ramey 2001, 2003).

One of the major celebrated arguments of RBC theory is that technology shocks are pro-cyclical. A positive technology shock will increase output, consumption, and employment. Yet this result is obtained from the empirical evidence, in which the technology shock is measured by the standard Solow residual. Like Gali (1999) and Francis and Ramey (2001, 2003), we find that if one uses the corrected Solow residual, the technology shock is negatively correlated with employment, and therefore the RBC model loses its major driving force (see chapters 5 and 9).

Puzzles to Be Solved

To sum up, we may say that the standard RBC model has left us with major puzzles. The first type of puzzle is related to the asset market and is often discussed under the heading of the equity premium puzzle. Extensive research has attempted to improve on this problem by elaborating on more general preferences and technology shocks. Chapter 6 studies in detail the asset price implication of the RBC model. The second puzzle is, as mentioned above, related to the labor market. The RBC model generally predicts an excessive smoothness of labor effort and wrong cross-correlation of labor effort with other macrovariables, in contrast to empirical data. Third, the RBC model predicts a significantly high positive correlation between technology and employment, whereas empirical research demonstrates, at least for business cycle frequency, a negative or almost 0 correlation. This has been named the technology puzzle. The first puzzle is studied in chapter 6 of this volume, and chapters 8 and 9 are mainly concerned with the latter two puzzles.

Of course numerous other puzzles arise when such an intertemporal decision framework is applied to macroeconomics. Particular problems arise—for example, for modeling asset markets and monetary and fiscal policy, or open economy issues that we do not discuss in this volume. Finally, future work on intertemporal decision models will face new challenges arising from the problem of the accuracy of the solution methods used when moving toward empirical applications of large-scale models.

PART I

SOLUTION AND ESTIMATION OF STOCHASTIC DYNAMIC MODELS