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Introduction

1.1 Dynamic General Equilibrium versus Traditional Macroeconomics

Modern macroeconomics seeks to explain the aggregate economy using theories based on strong microeconomic foundations. This is in contrast to the traditional Keynesian approach to macroeconomics, which is based on ad hoc theorizing about the relations between macroeconomic aggregates. In modern macroeconomics the economy is portrayed as a dynamic stochastic general equilibrium (DSGE) system that reflects the collective decisions of rational individuals over a range of variables that relate to both the present and the future. These individual decisions are then coordinated through markets to produce the macroeconomy. The economy is viewed as being in continuous equilibrium in the sense that, given the information available, people make decisions that appear to be optimal for them, and so do not knowingly make persistent mistakes. This is also the sense in which behavior is said to be rational. Errors, when they occur, are attributed to information gaps, such as unanticipated shocks to the economy.

A distinction commonly drawn is between short-run and long-run equilibria. The economy is assumed to be always in short-run equilibrium. The long run, or the steady state, is a mathematical property of the macroeconomic model that describes its path when all past shocks have fully worked through the system. This can be either a static equilibrium, in which all variables are constant, or, more generally, a growth equilibrium, in which in the absence of shocks, there is no tendency for the economy to depart from a given path, usually one in which the main macroeconomic aggregates grow at the same rate. It is not, therefore, the economy that is assumed to be in long-run equilibrium, but the macroeconomic model. The (short-run or long-run) equilibrium is described as general because all variables are assumed to be simultaneously in equilibrium, not just some of them, or a particular market, which is a situation known as partial equilibrium.

Individual decisions are assumed to be based on maximizing the discounted sum of current and future expected welfare subject to preferences and four constraints: budget or resource constraints, endowments, the available technology, and information. A central issue in DSGE macroeconomics is the intertemporal

nature of decisions: whether to consume today or save today in order to consume in the future. This entails being able to transfer today's income for future use, or future income for today's use. These transfers may be achieved by holding financial assets or by borrowing against future income. The different decisions are then reconciled through the economy-wide market system, and by market prices (including asset prices). Much of the focus of modern macroeconomics, therefore, is on the individual's responses to shocks and how these are likely to affect multiple markets simultaneously, both in the present and in the future. For example, the business cycle is attributed to such shocks.

Shocks are often treated as random variables unpredictable from the past. Consequently, dynamic general equilibrium (DGE) models are often referred to as dynamic *stochastic* general equilibrium models. As it is often simpler to carry out our analysis without explicitly including the stochastic features of a model, we will occasionally refer to DGE rather than DSGE models until we formally introduce stochastic elements in our discussion of the theory of finance in chapter 11.

Three main types of decision are taken by economic agents. They relate to goods and services, labor, and assets: physical assets (the capital stock, durables, housing, etc.) or financial assets (money, bonds, and equity)—each has its own economy-wide market. It is convenient to consider the decisions of individuals according to whether they are acting, in economic terms, as a household, a firm, or a government. Broadly, the decisions of the household relate to consumption, labor supply, and asset holdings. The firm determines the supply of goods and services, labor demand, investment, productive and financial capital, and the use of profits. Government determines its expenditures, taxation, transfers, base money, and the issuance of public debt. Financial firms, including the banks, coordinate the borrowing and savings decisions of these three agents via the financial markets.

A convenient starting point for the study of DSGE macroeconomic models is a small general equilibrium model, but one that includes the main macroeconomic variables of interest. It is based on a single individual who produces a good that can either be consumed or invested to increase future output and consumption. It is commonly known either as the Ramsey (1928) model or as the representative-agent model. This is a surprisingly useful characterization of the economy as it permits the analysis of a number of its key features—consumption and saving, saving and investment, investment and dividend payments, technological progress, the intertemporal nature of decisions, the nature of economic equilibrium, the short-run and long-run behavior of the economy (the business cycle and economic growth), and how prices, such as real wages and real interest rates, are determined—but without having to introduce them explicitly.

The basic Ramsey model can be roughly interpreted as that of a closed economy, without a market structure, in which the decisions are coordinated by a central planner. A first step toward greater realism is to allow decisions to be

decentralized. This requires us to add markets—which act to coordinate decisions, and thereby enable us to abandon the device of the central planner—and financial assets. Subsequent steps are to include a government, and hence fiscal policy, to introduce money, and hence a distinction between real and nominal variables, and to allow a foreign dimension (the current account, the balance of payments, and real and nominal exchange rates). At each stage the economy is analyzed as a general equilibrium system and the significance for the economy of each added feature can be studied. Because it highlights individual behavior, one of the main attractions of this approach is that it provides a suitable framework for analyzing economic policy through respecting the “deep structural” parameters of the economy, which are not usually changed by policy—unless, of course, they are policy parameters that are changed. This too is in contrast to traditional macroeconomic models, like the Keynesian model, which are not specified in terms of the deep structural parameters but by coefficients that may be changed by policy in a manner that is often unspecified or unknown.

1.2 Traditional Macroeconomics

Views on how best to analyze macroeconomic variables such as aggregate consumption, total output, and inflation have changed much in the last twenty-five years. Under the influence of Keynesian macroeconomics, the emphasis was on the short-run behavior of the economy, why the economy seemed to persist in a state of disequilibrium, and how best to bring it back to equilibrium, i.e., how to stabilize the economy. In studying these issues, it was common for each macroeconomic variable to be modeled one at a time in separate equations; only then were they combined to form a model of the whole economy. The Brookings macroeconometric model was constructed in exactly this way (Duesenberry 1965): in the first stage individual aggregate variables were allocated to separate researchers and then, in the second stage, their equations were collected together to form the complete macroeconometric model. As a result, macroeconomics tended to focus on the short-run behavior of the economy and did so using a partial-equilibrium approach that led to a compartmentalization of thought in which it was difficult to acquire an overall view of how the system as a whole was likely to behave in response, for example, to a change in an exogenous variable, such as a policy instrument, or to a shock. Consequently, it was sometimes difficult to take into account the wider and longer-term effects of policy—policies that may even have been designed to combat the shock. There was, therefore, a tendency for policy to be too narrowly conceived and analyzed.

The study of macroeconomics was prompted in large part by the Great Depression—the worldwide recession of the 1930s. One of Keynes’s original objectives in *The General Theory* (Keynes 1936) was to understand how such sustained periods of high unemployment could occur. From the beginning, therefore, interest was directed not so much to how the economic system behaved in long-run equilibrium, but to why it seemed to be misbehaving in

the short run by generating periods of apparent disequilibrium—in particular, departures from full employment—and to what, if anything, could be done about this. Until the last few years macroeconomic theory (and especially macroeconomic textbooks) has focused mainly on constructing models to explain this so-called disequilibrium behavior in the economy with a view to formulating appropriate stabilization policies to return the economy to equilibrium. The grounds for stabilization policy are that the economic system departs from equilibrium and, left to itself, would not return to equilibrium, or would do so too slowly. The aim of the policy intervention is to restore equilibrium, or to return the economy to equilibrium (or close to equilibrium) more quickly. This disequilibrium approach to macroeconomics tends to focus on individual markets and not the system as a whole. It also emphasizes the demand side of the economy. The outcome was a piecemeal, partial-equilibrium approach to macroeconomics. A corollary of the emphasis on disequilibrium was that equilibrium came to be regarded as a special, and less important, case.

1.3 Dynamic General Equilibrium Macroeconomics

The traditional approach to macroeconomics may be contrasted with the conception of DSGE macroeconomics that economic agents are continuously reoptimizing, subject to constraints, with the result that the macroeconomy is always in some form of equilibrium, whether short run or long run. According to this view, the short-run equilibrium of the economy may differ from its long-run equilibrium but, if stable, the short-run equilibrium will be changing through time and will over time approach the long-run equilibrium; but the only sense in which the economy can be in disequilibrium at any point in time is through basing decisions on the wrong information. From this perspective, even the view sometimes expressed that disequilibrium is a special case of DSGE macroeconomics is misleading. DSGE models assume that *ex ante* the economy is always in equilibrium.

Although for most economies macroeconomics has retained a focus on short-run behavior and stabilization, inspection of the path followed by gross domestic product (GDP) shows that the dominant feature is the growth in the trend of potential output; the loss of output due to recessions is almost trivial by comparison. This suggests that it is far more important to raise the rate of growth of potential output through supply-side policies than to move the economy back toward the trend path of potential output by demand-side stabilization policies.

The origins of DSGE macroeconomics lie in the work of Lucas (1975), Kydland and Prescott (1982), and Long and Plosser (1983) on real business cycles. Their aim was to explain the dynamic behavior of the economy (notably the autocovariances of real output and the covariances of output with other aggregate macroeconomic time series) based on a competitive rational-expectations equilibrium model that took its inspiration from models of economic growth.

The initial focus was on the role of technology shocks in generating the business cycle. The model used by Kydland and Prescott was, in essence, the model of Ramsey; that of Lucas included, in addition, government expenditures and money. Subsequent work extended the model in various ways in order to examine the effects of other types of shocks. We consider the principal results of this research in chapter 16. These issues are not, however, the sole concern of DSGE macroeconomics, or of this book.

A frequent motivation for constructing macroeconomic models, and one of the first questions usually asked of a model, is what it implies for economic policy. (A recent discussion of the usefulness of DSGE models in formulating policy is Chari and Kehoe (2006).) Nonetheless, it is important to realize that the aim of macroeconomics is not just to study policy issues. There are prior questions that should be asked, such as how the economy might behave if it were in equilibrium, and how it responds to changes in exogenous variables and to shocks. Finding the answers to these questions is a sufficient reason to study macroeconomics. Although it is common to ask what the policy implications of a macroeconomic theory are, with the implicit assumption that we are forever seeking to interfere in the economy, it is not always necessary to search for policies that alter the equilibrium solution, especially if we are unclear what the broader consequences might be. Arguably, simply trying to understand how the economy behaves is sufficient justification.

Much of our analysis will be on considering what sort of factors might disturb an economy's equilibrium, and how the economy responds to these. They may be changes in exogenous variables or shocks. They may be permanent or temporary, anticipated or unanticipated, real or nominal, demand or supply, domestic or foreign, and the response of the economy may be different in each case. The conclusions we reach are often very different from those based on traditional macroeconomic models. Shocks may be serially uncorrelated, but the intrinsic dynamic structure of the economy may result in them having persistent effects on macroeconomic variables. This is the cause of short-term fluctuations in the economy, and hence the basis of business-cycle theory.

DSGE models are forward looking and hence intertemporal. Current decisions are affected by expectations about the future. As a result, we use intertemporal dynamic optimization, in which people are treated as if they rationally process current information about the future when making their decisions. There is a premium on obtaining the correct information and on deciding how best to use it. These concerns are linked to the concept of rationality—another key feature of DSGE macroeconomics. The willingness of macroeconomists to make the assumption of rationality rapidly divided professional opinion into two camps. Traditional macroeconomics was based on the assumption of myopic decision making in which mistakes, even when realized, were often persisted in. The central idea behind rational expectations is that people do not make persistent mistakes once they are identified. This does not necessarily imply, as is often assumed, that people have more or less complete knowledge, for the mistakes

are largely the result of unanticipated information gaps or shocks. It is sufficient to suppose that mistakes are not repeated. As forward-looking decisions must be based on expectations of the future, they may be incorrect; decisions that seem correct *ex ante* may not therefore be correct *ex post*. As previously noted, only as a result of this type of mistake might it be appropriate to think of the economy as being in disequilibrium.

Recent research has suggested that a policy of intervention by the government tends to be most successful when the government has an informational advantage over the private sector. If the private sector is able to fully anticipate the intervention, then the policy may be less successful. This is mostly true when the intervention involves private rather than public goods. As the private sector would substitute public for private goods, in effect, households would be paying for these goods from taxes instead of after-tax income. In contrast, the provision of public goods leads to a net increase in output as total private benefits exceed total private costs. These arguments about government expenditures apply more generally, of course, and will be developed further below.

Another attraction of this intertemporal approach to macroeconomics is that it resolves a long-standing weakness in Keynesian economics. This concerns the way equilibrium is defined in dynamic macroeconomics. The problem goes back to Keynes's (1930) *A Treatise on Money*, in which the concept of equilibrium used was that of a flow equilibrium (savings equals investment). Keynes realized that his formulation of equilibrium was incorrect and wrote *The General Theory* partly in an attempt to correct this error (Keynes 1936). In *A Treatise on Money*, one variable (the interest rate) had the task of equilibrating two variables (savings and investment). Keynes's solution in *The General Theory* was to introduce a second variable (income). This allowed savings to be equal to investment for any possible values of savings and investment. Unfortunately, this is still an inappropriate concept of equilibrium, namely, a flow equilibrium. It is suggested by Skidelski (1992) that Keynes was never entirely happy with *The General Theory*. Perhaps this was because he realized that he had not fully solved the problem of macroeconomic equilibrium.

The correct concept of equilibrium is that of stock equilibrium and not flow equilibrium. Perhaps Keynes focused on the latter because he was principally interested in the short run and not in long-run equilibrium. In DSGE macroeconomic models individual preferences relate to consumption (a flow variable), but equilibrium in the economy is defined with reference to capital (a stock). There are an infinite number of possible flow equilibria—sometimes called temporary (or short-term) equilibria—but only one of these is consistent with the stock equilibrium. The problem is how to obtain this flow equilibrium. (We show that this is usually the unique saddlepath to equilibrium.) It is common in DSGE macroeconomics to start by deriving the stock equilibrium.

A crucial feature of the stock equilibrium is that it involves a forward-looking component and is not just backward looking. This introduces a vital distinction between economics and the natural sciences that in some ways makes

economics harder. Because people look forward when making decisions, there may be opportunities for others to manipulate strategically for their own benefit the information on which these decisions are based. The inanimate natural sciences, such as physics and chemistry, do not have such a forward-looking component in their dynamic structure, and therefore do not have this strategic dimension.

Stocks, or capital, consist of physical and financial capital. This provides a natural link between macroeconomics and finance. The theory of finance is largely concerned with pricing financial assets, notably bonds and equity. As financial assets play a crucial role in macroeconomics, and are sometimes substitutes in wealth portfolios for physical assets, asset-pricing theory is an essential component of macroeconomics and not something that may be omitted as in the past, or allowed to become a different discipline from macroeconomics.

A related issue is the unit of time. It is common, in both macroeconomics and finance, to conduct the analysis in continuous rather than discrete time—the convention we adopt here. Using continuous time does not prevent the use of discrete lags but it does imply that decisions are taken continuously. In part, the choice depends on the frequency of observation of the data. Continuous time is often a better approximation for financial decisions as events and much of the available data are high frequency, possibly very high frequency, such as minute by minute. Discrete time is better suited to most macroeconomics as neither the decisions nor the data are usually high frequency: they may be monthly, quarterly, or, for national income data, even annual. In practice, both continuous and discrete time are just approximations. It is therefore important to bear in mind that the unit of time used in our discrete-time analysis may relate to different units of calendar time, depending on the subject matter. For example, the units of time in growth theory or overlapping-generations models are longer than those in the analysis of floating exchange rates.

Prompted in part by the financial crisis of 2008, the DSGE approach to macroeconomics has recently come under heavy criticism. Writing in the *New York Times*, Krugman (2009) claims that the macroeconomics of the last thirty years is spectacularly useless at best and positively harmful at worst. He asserts that we are living through the dark age of macroeconomics in which the hard-won wisdom of the ancients has been lost. In his view:

The economics profession has gone astray because economists, as a group, mistook beauty clad in impressive-looking mathematics, for truth. Not only did few economists see the current crisis coming, but most important was the profession's blindness to the very possibility of catastrophic failures.

Skidelski (2009), a biographer of Keynes, expresses a similar view that is worth describing in more detail. He argues that macroeconomics since Keynes has become increasingly divorced from reality because it has ignored Keynes's fundamental insight that the future is uncertain. In Skidelski's opinion, uncertainty

colored much of Keynes's macroeconomics and led to the main differences between the economics of Keynes and all subsequent macroeconomic theory. Some of Keynes's better-known conclusions emanating from this are that

- it makes investment—which is forward looking—highly volatile, much more so than consumption, which is based more on current income and habit;
- in times of uncertainty it causes people to prefer holding money to other financial assets—Keynes's liquidity preference theory—and it makes monetary policy ineffective due to a liquidity trap;
- it implies that the emphasis should be put on the short run rather than the long run, which is subject to much greater uncertainty;
- related to this, assumptions should be realistic and appropriate for the present rather than selected in order to focus on the main factors likely to be dominant in the long run and to make the analysis more amenable to a mathematical treatment.

With the financial crisis in mind, Skidelski emphasizes that uncertainty cannot be reduced to calculable risk, thereby challenging not just modern macroeconomics but modern finance theory too.

How justified are these criticisms? While it is undoubtedly true that the future is uncertain, we still have to take decisions involving the long term, such as those concerning pensions, durable goods like houses and cars, and, for businesses, investment in buildings and machinery. These force us to take a view about the future and hence to make intertemporal decisions under uncertainty—a key feature of modern DSGE macroeconomics that seeks the best way to do this. Although some events may be unpredictable—even catastrophic, such as earthquakes (particularly if they are followed by tsunamis)—most shocks to the macroeconomy are open to being modeled as stochastic processes and hence becoming calculable risks. It is not clear, however, that the financial crisis was due to fundamental uncertainty. As argued in chapter 15, it was caused by human error, resulting from a failure to interpret and apply existing theories of economics and finance correctly. And the reason for using mathematics is to ensure that the analysis is carried out logically and hence accurately. In this book I have taken the view that, although there may be uncertainty about the stochastic processes affecting the economy, DSGE macroeconomics, in combination with modern financial theory, provides the best means we possess of trying to understand the macroeconomy.

Various other complaints are sometimes made about DSGE models. First, the models are far too simple to capture the full complexity of the economy, and as a result are of dubious value. Second, a comment made by some who are familiar with engineering, is that in general macroeconomic models are far too complex to be useful. The first opinion is easier for most people to sympathize

with than the second. However, engineering has found that it is necessary to find a way of simplifying matters in order to make progress. There may be a lesson in this for macroeconomics. It may provide a justification for the use of models that are designed to capture key features of the economy while retaining their simplicity by abstracting from unnecessary detail. The simplicity of macroeconomic models, commonly seen as a major weakness, may therefore be a potential strength. It is true that virtually all macroeconomic policy is based on a simplified model of the economy, and there is an obvious danger in applying the conclusions obtained from such models to situations where the simplifying assumptions are too distorting. This makes it advisable to take care to establish the robustness of the conclusions to departures from the model assumptions. Nonetheless, as in engineering, the simple models of macroeconomics can often be remarkably robust and, therefore, useful. DSGE macroeconomic models tend to be more complex than Keynesian models, but they are still essentially highly stylized. Given the complexity of the economy and the high level of abstraction of theory, perhaps the best that one can hope for from theory is something quite modest: that it provides the intuition necessary to understand why the economy behaves as it does and what consequences policy might have. In interpreting our analysis we should, therefore, bear in mind its limitations: that we are only using models of the economy and that these models are necessarily simplifying because to do otherwise would almost certainly mean making the analysis intractable. For another view of the relationship between macroeconomics and engineering, see Mankiw (2006).

An assumption often objected to is that of a representative-agent economy. An interesting argument against this simplification is that it commits the “fallacy of composition.” This asserts that if each individual attempts to do something, they end up achieving the reverse due to the aggregate consequences. The best-known illustration of this contradiction is Keynes’s example of households each trying to save more, with the result that aggregate consumption and output—and hence individual incomes—fall, causing savings to decrease rather than increase.

The problem with this particular example is that it illustrates the dangers of using a partial rather than a general equilibrium analysis. One might ask what caused this sudden desire to save more, and whether the aim is a temporary or a permanent increase in individual savings. If temporary, then, in a general equilibrium analysis, the additional supply of savings would be expected to reduce the cost of borrowing temporarily, thereby stimulating borrowing and consumption, and deterring an increase in savings. If permanent, then the fall in the cost of borrowing would make the cost of capital lower and so stimulate additional investment, raising the optimal level of the capital stock and hence output and income. A temporary shock would not be expected to affect the optimal level of the capital stock, and therefore investment. Alternatively, if the cause of the additional saving was the assumption that in the future a temporary negative shock would affect output in the economy, this would induce

forward-looking households to save more today in order to smooth consumption. A general equilibrium analysis, therefore, rather dispels the contradiction contained in the fallacy.

This does not, however, alter the fact that the assumption of a representative-agent economy is made to make the analysis more tractable. More advanced treatments of macroeconomic problems often allow for heterogeneity.

1.4 The Structure of This Book

This book is organized as a sequence of steps that extend the basic model in order to produce, by the end, a general picture of the economy that can be used to analyze its main features. The sequence starts with the basic closed-economy model and is followed by the introduction of growth, markets, government, the real open economy, money, price stickiness, asset price determination, financial markets, the international monetary system, nominal exchange rates, and monetary policy. The book concludes with a discussion of some empirical evidence on DSGE models. In view of the above strictures on the advantages of using simple models, rather than retaining each added feature for each subsequent step, thereby finishing up with a complex general model of the economy, we aim to return to the original model as closely as we can and add each new feature to that. In this way we aim to provide a toolbox that is suitable for understanding how the economy works and that is useful for macroeconomic analysis, rather than a fully specified macroeconomic model so complex that it can only be studied using numerical methods.

Our starting point, in chapter 2, is the basic dynamic general equilibrium centralized model for a closed economy expressed in real terms. Its purpose is to introduce the methodology of DSGE macroeconomics. Although the setting is simple and we assume perfect foresight, it provides a remarkably powerful representation of an economy that has been used to study a wide variety of problems in macroeconomics, including real business cycles. It captures the key problem of DSGE macroeconomics, namely, the intertemporal decision to either consume today or invest in order to accumulate capital and produce more for extra consumption in the future. This simple model illustrates the important distinction between stock equilibrium and the sequence of flow equilibria that bring this about subject to suitable stability conditions.

The steady-state solution of the basic model of chapter 2 is a static equilibrium. In chapter 3 we show how the basic model can be modified so that in steady state the economy may achieve balanced economic growth. As a result, we are able to reinterpret the basic static solution as a description of the behavior of the economy about its steady-state growth path. As it is simpler to analyze a model with a static equilibrium, in later chapters we ignore growth, where possible, in the knowledge that we can focus on the deviations of the economy from its growth path. If we require the full solution, we can add the growth path to the deviations from it.

We decentralize decision making in chapter 4 and include markets to coordinate these decisions. In this way we are able to study the joint decisions of households and firms and their interactions in goods, labor, and capital markets. We show that various prices—notably wages and the rate of return on capital—although not included explicitly in the basic model, are nonetheless present implicitly. We also discuss the relationship between households and firms, and how the profits of the firm generate the firm's total value, the value of a share, and dividend income to households who are the owners of firms.

We introduce government into the model in chapter 5. We discuss the basis of government expenditures and how best to finance them with debt and taxes. In the process we consider optimal debt and taxation policy and the sustainability of the fiscal stance. This discussion is extended in chapter 6 to cover the problem of time inconsistency in fiscal policy, and to introduce the overlapping-generations model. This is particularly useful for fiscal and other decisions involving time periods that are very long, such as that of a generation. We use this to study the increasingly important issue of how to finance pensions.

In chapter 7 we introduce the foreign sector. This has important consequences for the economy as it alters the economy's resource constraint. The economy is no longer constrained to consume only what it can produce itself. Domestic residents can then borrow from and/or invest abroad. All of this should result in a welfare improvement for the economy. Making the economy open introduces many new issues and variables, and so greatly complicates the basic model. For example, there is the allocation problem between domestic and foreign goods and services and the determination of their associated relative price (the terms of trade), the relative costs of living of different countries (the real exchange rate), and the sustainability of current-account deficits.

So far all variables have been defined in real terms. This is partly to show that money plays a minor role in most of the real decisions of the economy. In chapter 8 we study nominal magnitudes—including the general price level and the optimal rate of inflation—by introducing money into the closed economy. Our focus here is on what determines the demand for money and why this might be affected by interest rates. We also discuss the use of credit instead of money. Although in a partial-equilibrium view of the economy money appears to impose a real cost, we show that in general equilibrium money is far more likely to be neutral in its effect on real variables. This chapter paves the way for the later discussion of monetary policy as it covers a key channel in the monetary transmission mechanism, namely, how money and interest rates affect other variables via the money market. Later we consider whether money has real effects in the short run.

Up to this point it has been assumed that prices are perfectly flexible and adjust so that markets clear each period. This is often regarded as a major weakness of DSGE models compared with Keynesian models, which tend to stress the imperfect flexibility of prices, arguing that this causes a consequent lack of

market clearing. In chapter 9 we show how to introduce imperfect price flexibility into the DSGE model. We show how monopolistic competition in goods and labor markets may cause imperfect price flexibility and result in a cost to the economy in terms of lost output. In this way we are able to incorporate price stickiness yet retain the benefits and insights of the DSGE model. Such models are sometimes known as New Keynesian models. The principal remaining difference between Keynesian and DSGE macroeconomics is that in the DSGE framework we continue to assume that the economy is always in equilibrium—albeit a temporary, and not necessarily a long-run, equilibrium. Thus economic agents always expect to be in their preferred positions subject to the constraints they face, one of which is the information they possess. In this sense, even prices are chosen optimally. Having introduced price stickiness, we then consider how this affects the determination of the aggregate supply function, a key equation in the determination of inflation.

As a result of viewing the economy as always being in equilibrium *ex ante* (but not *ex post*), it becomes more difficult to explain unemployment that is involuntary. The obvious implication of being in equilibrium is that unemployment must be voluntary. In chapter 9—a new chapter for the second edition—we examine whether two well-known theories of unemployment—search theory and efficiency-wage theory—provide a satisfactory explanation of unemployment. We contrast these theories with an alternative explanation: that the persistence of unemployment is due to price and wage stickiness.

Chapters 11 and 12 are a notable departure from traditional treatments of macroeconomics as they consider the determination of asset prices, the behavior of financial markets, and the role of the bond market in the transmission of monetary policy. Once the preserve of finance, these issues are now increasingly recognized as essential components of economics and, in particular, of DSGE theory. After adding uncertainty due to stochastic features of the economy, the same basic model that we have used to analyze consumption, savings, and capital accumulation can be used to determine financial assets and asset prices. This provides an explanation of asset prices based on economic fundamentals as opposed to the usual approach in finance, namely, relative asset pricing. Consequently, asset prices are determined in conjunction with macroeconomic variables instead of in relation to other asset prices. The general equilibrium theory of asset pricing is set out in chapter 11 and it is specialized to apply to the bond, equity, and foreign exchange (FOREX) markets in chapter 12.

Before reaching chapter 11, we have, for the most part, ignored the fact that intertemporal decisions involve uncertainty about the future and are based on forecasts of the future formed from current information. Our analysis has therefore been conducted using nonstochastic, rather than stochastic, intertemporal optimization. This has allowed us to use Lagrange multiplier analysis instead of the more complicated stochastic dynamic programming. In general equilibrium asset pricing, uncertainty about future payoffs is a central feature of the analysis. The degree of uncertainty about each asset can be different.

It ranges from certain to highly uncertain payoffs. Assets with certain payoffs have risk-free returns; those with uncertain payoffs have risky returns that incorporate risk premia in order to provide compensation for bearing the risk. A key issue in asset pricing is the problem of determining the size of the risk premium that is required in order for risk-averse investors to hold a risky asset, i.e., the expected return on a risky asset in excess of the return on a risk-free asset.

In our previous discussion of the economy, in effect we treated savings as being invested in a risk-free asset. It may seem, therefore, that we must rework many of our previous results in order to allow for investing in risky assets. This would, of course, greatly complicate the analysis as it would necessitate the inclusion of risk effects throughout. We show in chapter 11 that this is not, in fact, necessary as all we need do is risk-adjust all returns, i.e., adjust all risky returns by subtracting their risk premium. This implies that we can continue to work with only a risk-free asset and to use nonstochastic optimization. Hence, most of the time we are able to ignore such uncertainty.

In chapter 7 we treat the nominal exchange rate as given and consider only the determination of the real exchange rate. In chapter 13 we analyze the determination of nominal exchange rates. As the exchange rate is an asset price (the relative price of domestic and foreign currency), we must use the asset-pricing theory developed in chapters 11 and 14. The no-arbitrage condition for FOREX is the uncovered interest parity condition, which relates the exchange rate to the interest differential between domestic and foreign bonds. Macroeconomic theories of the exchange rate are based on how macroeconomic variables affect interest rates and, through these, the exchange rate. Before embarking on our analysis of exchange rates in chapter 13, we discuss the effect of different international monetary arrangements on the determination of exchange rates.

Having covered the principal components of the DSGE model, in chapter 14 we study the use of the model in formulating monetary policy. Our analysis is based on the New Keynesian model of inflation. To bring out its new features we contrast this with the traditional Keynesian analysis of inflation. We consider alternative ways of conducting monetary policy: via exchange rates, money-supply targets, and inflation targeting. In the process we extend our discussion of the determination of exchange rates in chapter 13 by developing a New Keynesian model of exchange rates. We then focus solely on inflation targeting. We examine the optimal way to conduct inflation targeting both in a closed economy and in an open economy with a floating exchange rate. We conclude our discussion of monetary policy by proposing a simple model of monetary policy in the eurozone, where there are independent economies but a single currency, and hence a single interest rate for all economies.

In chapter 15—another new chapter—we develop the interconnections between macroeconomics and finance further. We consider several issues: we discuss borrowing constraints and default, the role of the banking and financial systems in the financial crisis of 2008–11; we examine alternative models of the

banking sector, their ability to account for the financial crisis, and how best to incorporate a banking sector in a DSGE model; and we propose a DSGE model with default risk.

The final chapter, chapter 16, presents a brief account of how well simple DSGE models perform in explaining the main stylized facts of the economy, and tries to identify some of their shortcomings. We base our discussion on a small selection of studies of the real business cycle that is designed to illustrate the principal issues rather than to be fully comprehensive. The main focus in this literature is on the ability of these models, whether they are for a closed or an open economy, to explain the business cycle solely by productivity shocks. We then examine a DSGE model of the economy that claims to provide a better explanation of economic fluctuations by including various market imperfections and frictions that introduce different types of shocks, including monetary-policy shocks. The attraction of this approach is that monetary shocks may then have persistent real effects. It has been suggested, however, that such models suffer from a lack of identification as these market imperfections are open to more than one interpretation. We discuss this issue together with the more general question of whether DSGE models are identified. Given the diversity of DSGE models considered in this book, we complete the chapter with some reflections on how one might decide which features to include when constructing a DSGE model.

Finally, we provide a mathematical appendix in which we explain the main mathematical results and techniques we have used in this discussion of contemporary macroeconomic theory based on DSGE models.

There are also exercises (with solutions) for students and these are available on the Princeton University Press web site at

<http://press.princeton.edu/titles/9743.html>