# Global and National Macroeconometric Modelling: A Long-Run Structural Approach

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# Preface

National and global macroeconometric modelling has had a long and venerable history in the UK, with important implications for macroeconomic policy in general and monetary policy in particular. It is an activity that involves sustained research input of several investigators with a variety of skills. The present work is not an exception and its completion has required the enthusiasm and commitment of a large number of individuals and institutions. It was given initial impetus by funding from the UK's Economic and Social Research Council (Grant no. L116251016) and from the Newton Trust of Trinity College, Cambridge (under Anil Seal), to whom we are very grateful. They funded a project on 'Structural Modelling of the UK Economy within a VAR Framework using Quarterly and Monthly Data', conceived and originally housed in the Department of Applied Economics (DAE) at the University of Cambridge in the mid-1990s. The authors all worked at Cambridge at the time, along with Brian Henry and Martin Weale who were also co-applicants on the project. Although the team dispersed over the years (Garratt to Leicester and then Birkbeck; Henry to LBS and then Oxford; Lee to Leicester; Shin to Edinburgh and Leeds; and Weale to the National Institute), we remain very grateful for the resources and congenial atmosphere provided by co-researchers and colleagues during our time working at and visiting the DAE.

The research associated with the project extended well beyond the original intentions of the funded project, however, and has benefited from the help and expertise of many friends and colleagues. We are particularly grateful to Richard Smith and Ron Smith, who have collaborated with us and made essential contributions to various aspects of the work in the book, and we have received invaluable comments from Manuel Arrelano, Michael Binder, Carlo Favero, Paul Fisher, Clive Granger, David Hendry, Cheng Hsiao, George Kapetanios, Adrian Pagan, Bahram Pesaran, Til Schuermann, James Stock, Ken Wallis and Mike Wickens. The book draws on material from a variety of our published journal articles also, and we are particularly grateful to the constructive and enlightening comments

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# 1 Introduction

Macroeconometric modelling is at the heart of decision-making by governments, industrial and financial institutions. Models are used to organise and describe our understanding of the workings of the national and global economies, provide a common framework for communication, predict future economic developments under alternative scenarios, and to evaluate potential outcomes of policies and external events. This book aims to contribute to this important literature by providing a detailed description of the 'long-run structural modelling approach' applied to modelling of national economies in a global context. The modelling approach builds on recent developments in macroeconomic theory and in time series econometrics, and provides a transparent framework for forecasting and policy analysis. The book covers theoretical as well as practical considerations involved in the model-building process, and gives an overview of the econometric methods.

The modelling strategy is illustrated through a detailed application to the UK economy. This application is intended to be of interest in its own right, as well as providing a blueprint for long-run structural modelling by potential users of the approach in other contexts. To this end, we also provide the data and computer code employed in the UK modelling exercise to illustrate the steps taken and to facilitate replication of the methods and their application to other datasets. Hence, the book aims to provide a description of the construction and use of the UK macroeconometric model in sufficient detail so that it will be of use to practitioners who might wish to undertake a similar sort of exercise; users are persuaded of the cohesion between the modelling activity and the end uses of the model; and the policy analyses and forecasts that are presented are readily interpretable and of direct use by decision-makers. We also describe various extensions of the modelling exercise, including an explanation of how the modelling approach could be applied to develop a global macroeconometric model, developed from scratch or accommodating the UK model, and an explanation of how the UK model could be used to focus on specific features of the national economy which might be of specific interest to particular decision-makers.

In describing our modelling activities, we address directly the anxieties of those who make use of macroeconomic models but who recognise also the uncertainties and ambiguities involved in modelling and associated forecasting. So, in explaining our strategy, we make an explicit distinction between those elements of economic theory that we believe with some degree of confidence (usually associated with the long-run properties of the economy) and those elements for which economic theory is less clear-cut (on the short-run dynamics arising out of the precise sequencing of decisions, for example). We also compare our views on the working of the macroeconomy with those of alternative modelling approaches, noting the areas in which there is broad agreement and those in which there is less consensus. We note too that, once we have estimated our model, we can test formally the validity of hypotheses implied by our specific economic theory. This discussion aims to place our modelling approach in context, trying to reconcile it with the work of other macromodellers. And it aims to reassure the reader that the modelling approach is securely anchored to a firm and transparent theoretical base.

The distinction drawn between confidently held views and less confidently held beliefs on the underlying economic theory also informs our interpretation of the model and its dynamic properties. Hence, there are some properties of the model which reflect the influence of the views on the long-run relationships between variables implied by economic theory. But other aspects of the dynamic properties of the model are interpretable only if one has a particular view on the short-run processes driving decision-making, and these views may be more contentious. By explicitly drawing these distinctions, we are able to provide more reliable and informed predictions on the outcome of policies and on the reactions of the macroeconomic variables of interest to external events and to relate the model predictions directly to the underlying economic theory.

Most importantly, when considering the use of models in forecasting, we emphasise the needs of decision-makers and other end-users. For this reason, we do not present our forecasts only in the form of point forecasts with confidence intervals, as is usually the case, but provide tables and graphs of 'probability forecasts'. These measures refer to events considered





to be of interest to decision-makers (such as 'recession' or 'low inflation' at various forecast horizons, for example) and indicate the likelihood of these events taking place according to the estimated model. The probability forecasts convey the uncertainty surrounding the model's forecasted outcomes in a clear and transparent way.

## 1.1 Historical background

Macroeconometric modelling in the UK and elsewhere has undergone a number of important changes over the past twenty or thirty years, driven by developments in economic and econometric theory as well as changing economic circumstances. One important impetus in this process was Lucas' (1976) critique of macroeconometric policy evaluation, which resulted in widespread adoption of the rational expectations methodology in macroeconomic models. It also provoked considerable scepticism concerning the use of large-scale macroeconometric models in policy analysis and initiated the emergence of a new generation of econometric models explicitly based on dynamic intertemporal optimisation decisions by firms and households. At the same time, Sims' (1980) critique raised serious doubts about the traditional, Cowles Commission approach to identification of behavioural relations, which had been based on what Sims termed 'incredible' restrictions on the short-run dynamics of the model. This critique generated considerable interest in the use of vector autoregressive (VAR) models in macroeconometric analysis.[1] A third impetus for change in the way in which macroeconometric modelling has been undertaken came from the increased attention paid to the treatment of non-stationarity in macroeconomic variables. The classic study was that by Nelson and Plosser (1982), who showed that the null hypothesis of a unit root could not be rejected in a wide range of macroeconomic time series in the US. This resurrected the spectre of spurious regression noted originally by Yule (1926), Champernowne (1960), and more recently by Granger and Newbold (1974). Subsequently, the work of Engle and Granger (1987), Johansen (1991) and Phillips (1991) on cointegration showed possible ways of dealing with the spurious regression problem in the presence of unit root variables, with important consequences for macroeconometric modelling in particular.

[1] Sims' critique also extends to the identification of rational expectations models.

## 1.2 Alternative modelling approaches

Different purposes require different models. A purely theoretical model may be adequate for some purposes while, for other purposes, a purely statistical description of the data may be adequate. However, in many cases, we need to combine theoretical coherence with a good description of the data. This synthesis has taken four main forms. *First*, there are large-scale macroeconometric models such as the various vintages of HM Treasury's model of the UK economy and the Federal Reserve Board's model of the US economy. These models can contain hundreds of variables and equations and are typically built on detailed sub-models of the various sectors of the macroeconomy. The large-scale models have made many important innovations over the years but, by their very nature and because of the questions they are designed to address, they have evolved slowly. Hence, they have essentially followed the tradition of the Cowles Commission, making a distinction between exogenous and endogenous variables and imposing restrictions, often on the short-run dynamic properties of the model, in order to achieve identification. The parameters have been typically estimated by least squares or by instrumental variables methods, and full information estimation of the model parameters has rarely been attempted.

*Secondly*, following the methodology developed by Doan, Litterman and Sims (1984), Litterman (1986), and Blanchard and Quah (1989), there are unrestricted, Bayesian, and 'structural' vector autoregression (VAR) specifications that are used extensively in the literature. VAR and Bayesian VARs (BVAR) are primarily used for forecasting. The structural VAR approach aims to provide the VAR framework with structural content through the imposition of restrictions on the covariance structure of different types of shocks. The basis of the structural VAR analysis is the distinction made between shocks with temporary (transient) effects from those with permanent effects which are then related to economic theory in a rather loose manner by viewing the two types of shocks as demand and supply type shocks, for example. The approach does not attempt to model the structure of the economy in the form of specific behavioural relationships. Its application is also limited to relatively small models where the distinction between the two types of shocks is sufficient to deliver identification. The particular application considered by Blanchard and Quah to illustrate their approach, for example, is based on a bivariate VAR in real output and the rate of unemployment.





The *third* approach is closely associated with the Dynamic Stochastic General Equilibrium (DSGE) methodology originally employed in the Real Business Cycle literature. This approach developed following the seminal work of Kydland and Prescott (1982) and Long and Plosser (1983), and provides an explicit intertemporal general equilibrium model of the economy based on optimising decisions made by households and firms. Originally, the emphasis of these models was on real factors (*e.g.* productivity shocks) but more recently the 'New Keynesian DSGE models' have been developed to allow for monetary policy rules, adjustment costs, heterogeneity, and endogenous technological progress, for example, and also to accommodate nominal rigidities.[2] In consequence, the differences between the DSGE and the most recent incarnations of traditional macroeconometric models have become less pronounced. Also many of the DSGE models can be approximated by restricted VAR models, which also renders them more comparable with other modelling approaches.[3]

The *fourth* approach, and the one which we aim to promote in this book, is the 'structural cointegrating VAR' approach. This approach is based on the desire to develop a macroeconometric model that has transparent theoretical foundations, providing insights on the behavioural relationships that underlie the functioning of the macroeconomy. Implicit in the modelling approach is the belief that economic theory is most informative about the long-run relationships, as compared to the short-run restrictions that are more contentious. The approach allows testing of the over-identifying restrictions on the long-run relations and provides a statistically coherent framework for the analysis of the short run. At the practical level, the approach is based on a log-linear VARX model, where the familiar VAR model is augmented with weakly exogenous variables, such as oil prices, and country-specific foreign variables.[4] On the assumption that the individual macroeconomic series have a unit root, each of the long-run relationships derived from theory is associated with a cointegrating relationship between the variables, and the existence of these cointegrating relationships imposes restrictions on a VAR model of the variables. Hence, the approach provides an estimated structural model of the macroeconomy, in which the only restrictions on the short-run

[2] See Section 2.3 for details.

[3] See, for example, Kim and Pagan (1995), and Christiano *et al.* (1998). New Keynesian versions of the DSGE models have also been developed successfully by Smets and Wouters (2003) and Christiano *et al.* (2005).

[4] The econometrics of VARX models are described in detail in Chapter 6.

dynamics of the model are those which are imposed through the decision to limit attention to log-linear VARX models with a specified maximum lag length.[5] The work of King *et al.* (1991), Gali (1992), Mellander *et al.* (1992) and Crowder *et al.* (1999) is in this vein, although our own work has shown the flexibility of the approach, including the first attempts to use the structural cointegrating VARX modelling approach to build national and global macroeconometric models.[6]

It is worth noting at the outset that, while the approach that we advocate emphasises the importance of long-run restrictions, it is entirely possible to investigate also the validity and implications of specific theories on the short run while still following our modelling strategy. Of course, this would require the imposition of further restrictions on the cointegrating VAR, but these additional short-run restrictions can be imposed without reference to the restrictions imposed on the long run and have no bearing on the influence of the long-run restrictions (or *vice versa*). Indeed, there are many questions of interest that necessitate the use of a macroeconometric model and which require the investigator to take a view on the short-run behaviour of the macroeconomy; investigating the effects of monetary policy, for example. This can be done and, indeed, we shall devote some time in the book to the examination of monetary policy using our estimated model for the UK.

## 1.3 The long-run modelling approach

The long-run structural modelling approach begins with an explicit statement of a set of long-run relationships between the macroeconomic variables of interest, derived from macroeconomic theory, including key arbitrage and solvency conditions for example. These long-run relationships are then embedded within an otherwise unrestricted VARX model, augmented appropriately with country-specific foreign variables. The VARX model is then estimated, using recently developed econometric

[5] Hence, the approach cannot capture directly the possibility that some of the macroeconomic relationships contain a moving average component or involve important asymmetries in adjusting to shocks, for example. The impact of these influences on the dynamics of the macroeconomy can only be approximated within the context of a *non-linear* dynamic model.

[6] The work of these earlier papers is more limited in scope. The models of King *et al.* (1991), Gali (1992) and Crowder *et al.* (1999) are closed economy models unsuitable for modelling a small open economy such as the UK. The model of Mellander *et al.* (1992) attempts to capture the open nature of the Swedish economy only by adding a terms of trade variable to the consumption–investment–income model analysed by King *et al.* (1991).





methods, to obtain an augmented cointegrating VAR model which incorporates the structural long-run relationships. This direct procedure also yields theory-consistent restrictions on the intercepts and/or the trend coefficients in the VAR, which play an important role in testing for cointegration and co-trending, as well as for testing restrictions on the long-run relations.

The approach shares common features with many applications of cointegration analysis. However, it is distinct because many applications of cointegration analysis start with an unrestricted VAR and then (sometimes) impose restrictions on the cointegrating relations, without a clear *a priori* view of the economy's structural relations. This latter more statistical approach is likely to be applicable when there exists only one cointegrating relationship among the variables in the VAR. When the number of cointegrating relations are two or more, without a clear and comprehensive theoretical understanding of the long-run relations of the macroeconomy, identification of the cointegrating relations and the appropriate choice of intercepts/trends in the underlying VAR model will become a very difficult, if not an impossible, undertaking. By beginning the analysis with an explicit statement of the underlying macroeconomic theory, the structural cointegrating VAR approach that we employ places the macroeconomic theory centre-stage in the development of the macroeconometric model.

The long-run structural approach has a number of other strengths in undertaking national and global macroeconometric modelling too. Being based on a cointegrating VAR with fully specified long-run properties, the estimated model possesses a transparency which is frequently lost in larger macromodels and our approach ensures that the resultant macromodel has a long-run structural interpretation. Further, by clarifying the relationship between economic theory and the short- and long-run restrictions of our model, our approach makes clear the difficulties involved in interpreting the effects of shocks in general, and in the analysis of impulse responses in particular. And our approach allows for a fairly general dynamic specification, and avoids some of the difficulties involved in other modelling approaches where a tight economic theory is used to impose very rigid restrictions on the short-run dynamics at the expense of fit with the data.[7]

The UK model that we present as the detailed illustration of our approach focuses on five domestic variables whose developments are widely regarded

[7] See, for example, Kim and Pagan's (1995) discussion of some of the early DSGE models.

as essential to a basic understanding of the behaviour of the UK macroeconomy; namely, output, prices, the nominal interest rate, the exchange rate and real money balances. It also contains four foreign variables: foreign output, the foreign price level, the foreign interest rate, and oil prices. The analysis gives a forum with which to illustrate further strengths of our modelling approach, providing insights on the UK from at least three perspectives. *First,* the econometric methodology that has been developed provides the means for testing formally the validity of restrictions implied by specific long-run structural relations within a given macromodel. The ability to test rigorously the validity of long-run restrictions implied by economic theory within the context of a small and transparent, but reasonably comprehensive, model of the UK macroeconomy is an important step towards an evaluation of the long-run underpinnings of alternative macrotheories. As such we test and implement an approach standard in theory but rare in practice. *Second,* our approach allows an investigation of the short-run dynamic responses of the model to shocks, while ensuring that the effects of the shocks on the long-run relations eventually vanish. This provides an important insight into the dynamics of cointegrating models where shocks have permanent effects on the levels of individual variables in the model. The methods employed enable us to undertake realistic policy evaluation exercises following one of two routes. The first route imposes no restrictions on the short-run dynamics of the model and investigates the model properties using 'generalised impulse response analysis'. This route avoids the strictures of Sims' critique and provides insights on the macroeconomy's dynamic responses which, unlike the orthogonalised impulse responses, are invariant to the order of the variables in the underlying VAR. The second route supplements the long-run restrictions with additional restrictions based on theorising on the short run. This route is susceptible to the criticisms of Sims and requires strong assumptions to be made on issues which are not uncontentious. But the route allows us to investigate the impact of very specific policy innovations (*e.g.* monetary policy shocks) and other external events (*e.g.* oil price innovations). And *third,* the relative simplicity of the cointegrating VAR model enables us to generate forecasts not just of the most likely outcomes of our macroeconomic variables, but also to generate forecasts of the likelihood of various events taking place and to investigate the sources of uncertainty surrounding these forecast probabilities. Hence, for example, we are able to evaluate the likelihood of the Bank of England hitting its inflation target over the near or longer term, and whether this is compatible with avoiding recession. Hence, our approach relates





the forecasts to the underlying properties of the macroeconomic model and presents the forecasts in a way which is helpful to those agents for whom the performance of the UK economy is an important influence on decision-making.

## 1.4 The organisation of the book

The book can be considered to be in three parts. In the first part, consisting of Chapters 2–7, we discuss the way in which economic theory and econometric analysis can be brought together to construct a macroeconometric model in which the long-run relationships are consistent with economic theory and where the short-run dynamics have an interpretation. The second part, consisting of Chapters 8–9, is devoted to the practical detail of estimating a long-run structural macroeconometric model, illustrated by a detailed description of the estimation of a model of the UK macroeconomy. And in the third part, consisting of Chapters 10–13, we discuss the interpretation and use of long-run structural macroeconometric models, describing the uses of the illustrative UK model along with extensions of the modelling activity to investigate global macroeconometric models and other specified issues in a national macroeconometric context.

In more detail, Chapter 2 briefly describes some alternative approaches to macroeconometric modelling, focusing primarily on their long-run characteristics and the consensus that has developed surrounding desirable long-run properties. Chapter 3 describes a framework for macroeconometric modelling which draws out the links with economic theory relating to the long run and with theory relating to the short run. The chapter elaborates a modelling strategy that can be employed to accommodate directly the theory of the long run and notes the ways in which short-run theory can also be accommodated. It also reviews the recent literature on modelling short-run dynamics, highlighting the difficulties in obtaining consensus on appropriate short-run restrictions and commenting on the approaches taken in the literature in examining policy shocks in general and monetary policy in particular. Chapter 4 describes a specific theoretical framework for macroeconomic modelling of a small open economy that can be embedded within a macroeconometric model, noting the testable restrictions on the long-run relations suggested by the theory. Complementing this, Chapter 5 explores a set of identifying restrictions on the short-run dynamics that might be used to supplement the long-run restrictions if the model is to be used to investigate the effect of economically meaningful shocks. Chapter 6 then briefly reviews the econometric methods needed for the empirical analysis of cointegrating VAR models, including new material (on the conditions under which error correction models are mean-reverting, for example) that are particularly useful in practical macroeconometric modelling. Finally in this part, Chapter 7 provides an introduction to the interpretation and estimation of probability forecasts which we consider to be a particularly useful method for presenting forecasts.

The part of the book concerned with the practical construction of the illustrative model of the UK economy begins with Chapter 8, which provides an overview of the data. Chapter 9 describes the empirical work underlying the construction of the UK model, discusses the results obtained from testing its long-run properties, and compares the model with benchmark univariate models of the variables. This description of the modelling work not only provides one of the first examples of the use of these cointegrating VAR techniques in an applied context, but it also includes a discussion of bootstrap experiments designed to investigate the small sample properties of the tests employed.

The final part of the book is concerned with the use of long-run structural macroeconometric models. It begins with Chapter 10, which discusses the dynamic properties of the estimated model. Chapter 11 is concerned with forecasting and prediction based on the model. Here we elaborate the notion of probability forecasting, which provides a useful means of conveying the uncertainties surrounding forecasts obtained from the model, and illustrate the usefulness of probability forecasts with reference to the Bank of England's inflation targets and the UK's growth prospects. Chapter 12 describes some recent extensions of the model and some other applications, including an introduction to the development of a model of the global macroeconomy using the same modelling approach.

Finally, in the appendices, we provide an account of the construction and sources of the data plus instructions on how to replicate the results presented in the empirical sections of the book. Much of the modelling work described in the book can be undertaken using Pesaran and Pesaran's (1997) econometric package *Microfit*. But for those who prefer to work with a programmable language, to adapt some of the procedures for example, we provide in the appendices also a simple manual for the use of a set of





computer programs written in *Gauss* that can be used to replicate or extend the analysis of the book too. The data and code are available through the authors' webpages. It is worth noting that the use of the programs, as described in the manual, is relatively straightforward to follow, although the user will need some familiarity with *Gauss* to implement them.

# 2

# Macroeconometric modelling: Alternative approaches

This chapter provides an overview of the main approaches to macroeconometric modelling, focusing in particular on the implications of the different approaches for modelling the long run. We discuss the 'structural cointegrating VAR' approach to macroeconometric modelling in general terms and compare it to other approaches currently followed in the literature; namely, the large-scale simultaneous equation macroeconometric models, structural VARs, and the dynamic stochastic general equilibrium (DSGE) models. The primary purpose of the review is to ascertain the extent to which there is a consensus on the desired long-run properties of a macroeconometric model and to compare the effectiveness of the different approaches to macroeconomic modelling in their attempts to test and incorporate these long-run properties into models in practice.

## 2.1 Large-scale simultaneous equation models

Large-scale simultaneous equation macroeconometric models (SEMs) have a long history and can be traced back to Tinbergen and Klein and the subsequent developments at the Cowles Commission. Prominent examples of large-scale models include the first and second generation models developed at the Federal Reserve Board (see, for example, Ando and Modigliani, 1969, Brayton and Mauskopf, 1985, and Brayton and Tinsley, 1996), Fair's (1994) model of the US economy, Murphy's (1988, 1992) model for Australia, and the various vintages of models constructed for the UK at the London Business School (LBS), the National Institute of

Economic and Social Research (NIESR), HM Treasury (HMT), and the Bank of England (BE).[1]

The relatively poor forecasting performance of the large-scale models in the face of the stagflation of the 1970s, in conjunction with the advent of rational expectations and the critiques of Lucas (1976) on policy evaluation and Sims (1980) on identification, brought about a number of important changes in the development and the use of large-scale SEMs throughout the 1980s and subsequently. Important developments have taken place in three major areas.[2] *First*, in response to Sims' criticism of the use of 'incredible' identifying restrictions involving short-run dynamics, and under the influence of developments in cointegration analysis (*e.g.* Engle and Granger, 1987), a consensus has formed that the important aspect of a structural model is its long-run relationships, which must be identified without having to restrict the model's short-run dynamics. *Second*, in response to the criticism that large-scale models paid insufficient attention to the micro-foundations of the underlying relationships and the properties of the macroeconomic system considered as a whole, there is now a greater use made of economic theory in the specification of large-scale models. And *third*, in response to the criticisms of Lucas, considerable work has been undertaken to incorporate rational expectations (RE), or strictly speaking model consistent expectations, into large-scale macromodels.

Under the influence of these developments, more recent generations of large-scale models have shared a number of important features. Almost invariably, the models have comprised of three basic building blocks: equilibrium conditions, expectations formation, and dynamic adjustments. The equilibrium conditions have been typically derived from the steady state properties of a Walrasian general equilibrium model, and there seems to be clear evidence of a developing consensus on what constitutes the appropriate general equilibrium model for characterising the long-run relations built around utility maximising households and profit-maximising firms facing appropriate budget and technology constraints.

1 Bodkin *et al.* (1991) provide a comprehensive survey of the history of macroeconometric model building. The evolution and the development of macroeconometric modelling at the Federal Reserve Board is reviewed by Brayton *et al.* (1997). For the UK these developments were documented in a series of volumes produced by the ESRC Macroeconomic Modelling Bureau (see, for example, Wallis *et al.* 1987). Further reviews of the modelling in the UK and elsewhere can be found in Smith (1994), Wallis (1995) and Hall (1995).

2 A detailed discussion of these developments in the case of the UK practice can be found in Hall (1995). Similar arguments have also been advanced by Brayton *et al.* (1997) in the case of the US experience.





This consensus side-steps the Sims critique by focusing on the long run and remaining agnostic on short-run dynamics.

Despite the progress made, and the growing consensus on what constitutes best practice in macroeconometric modelling, large-scale models have continued to be viewed with some scepticism by some, particularly in the area of policy analysis.[3] The complexity of the interactions of different parts of a large dynamic model means that the accumulated response of the macroeconomy to a particular shock or change in a given exogenous variable can be difficult to interpret, particularly as far as their effects on the long-run relations are concerned.[4] It is also difficult to identify and correct for misspecification in large-scale models, as attempts to fix one part of the model can have far reaching (and often unpredictable) consequences for the properties of the overall model.[5] Furthermore, as far as estimation is concerned, full information methods are often not an option given the size of the models. With these difficulties in mind, it has been argued that it is simply not possible for large-scale models to follow a best practice approach because of their size and complexity.

These difficulties are particularly apparent in the modelling exercises undertaken to consider global interactions. One of the first attempts at global linkages was Larry Klein's Project Link adopted by the United Nations which linked up traditional large-scale macroeconometric models developed originally for national economies. Other examples include the IMF's MULTIMOD multi-regional model (Laxton *et al.* (1998)) and the National Institute's Global Econometric Model (NiGEM) which estimates/calibrates a common model structure across OECD countries, China and a number of regional blocks and the IMF's MULTIMOD. The country/region-specific models in NiGEM are still large, each comprised of 60–90 equations with 30 key behavioural relationships.[6] These contributions provide significant insights into the interlinkages that exist among the major world economies and have proved invaluable in global forecasting. However, there are important weaknesses in the models. For example,

3 See, for example, Whitley (1997).

4 Innovative methods for characterising and summarising SEM's short-run and long-run properties have been developed to address this problem, however, primarily through stochastic simulation methods. See, for example, Wallis *et al.* (1987), Turner (1991) and Wallis and Whitley (1987). Methods for the analysis of the long-run properties of large macroeconometric models have also been developed by Murphy (1992), Fisher *et al.* (1992), and Wren-Lewis *et al.* (1996).

5 See, for example, the empirical exercise of Fisher *et al.* (1992) relating to the current account balance reaction to nominal exchange rate changes in the models developed by NIESR, LBS, BE and HMT at that time.

6 For a recent detailed account, see Barrell *et al.* (2001).

as argued in Pesaran, Schuermann and Weiner (2004), these models do not typically address the financial linkages that exist among the world's major economies. Moreover, they can be rather cumbersome to use in practice and the interlinkages of the different relations in different country models are often difficult to interpret.[7]

To summarise, while important progress has been made in the construction and use of large-scale SEMs, it is still often argued that these models are subject to a number of limitations that arise primarily from their large and complex structure. As Brayton *et al.* (1997) conclude: 'Large-scale macromodels are by their nature slow to evolve.' Simultaneous estimation and evaluation of such models is currently computationally prohibitive and, given the available time series data, may not be even feasible. A full integration of theory and measurement has proved elusive to large-scale model builders. Despite the imaginative attempts made over the past two decades, it remains a formidable undertaking to construct a theory-consistent large-scale macroeconometric model which has transparent long-run properties and fits the data well.

## 2.2 Unrestricted and structural VARs

### 2.2.1 *Unrestricted VARs*

The unrestricted VAR approach introduced into macroeconometrics by Sims (1980) stands at the other extreme to large-scale models. It focuses on modelling a relatively small set of core macroeconomic variables using a VAR specification with particular emphasis on the statistical fit of the model to the data possibly at the expense of theoretical consistency, both from a short-run and a long-run perspective. Sims' objective was to investigate the dynamic response of the system to shocks (through impulse response functions) without having to rely on 'incredible' identifying restrictions, or potentially controversial restrictions from economic theory. This strategy eschews the need to impose long-run relationships on the model's variables, and relies exclusively on time series observations to identify such relationships if they happen to exist.

According to the Wold decomposition theorem, all covariance stationary processes can be written as the sum of a deterministic (perfectly predictable) component and a stationary process possessing an infinite order

[7] The global VAR model of Pesaran, Schuermann and Weiner (2004) adopts the structural cointegrating VAR approach to developing a model to analyse global financial and real interactions. As explained in Section 3.4 and illustrated in Section 12.2, this analysis provides the modelling outcome with considerably more transparency.





moving average (MA) representation.[8] Restricting attention to 'invertible' processes,[9] one obtains a unique MA representation, also known as the 'fundamental' representation which fully characterises the sample autocorrelation coefficients. Such a fundamental representation can be approximated by a finite order vector autoregressive moving average (VARMA) process. However, estimation of VARMA models poses important estimation problems, particularly when the number of variables in the VARMA model is relatively large. For this reason, Sims chooses to work with a finite order VAR model which is much simpler to estimate, but involves further approximations. To perform impulse response analysis, Sims' approach then requires the use of a Choleski decomposition of the variance covariance matrix of the model's innovations/shocks. This enables the MA representation to be written in terms of orthogonalised innovations. It is the responses of the macroeconomic variables to these orthogonalised shocks that are described in Sims' orthogonalised impulse responses.

This approach to modelling has been subject to a number of criticisms (see, for example, Pagan, 1987), some of which are worth noting here. First, the approach requires care in the initial stages in the choice of transformation of the data to achieve stationarity. In particular, it is important that economically meaningful, and statistically significant, relations are not excluded from the analysis at this stage by the choice of transformation. For example, a VAR model in the first differences of $I(1)$ variables is mis-specified if there exists a cointegrating relationship between two or more of the $I(1)$ variables. Second, care is needed in the choice of variables to be included in the VAR analysis, and it is difficult to imagine how this choice could be made without reference to some underlying economic theory. And third, since the choice of the Choleski decomposition is not unique, there are a number of alternative sets of orthogonalised impulse responses which can be obtained from any estimated VAR model. A particular choice of orthogonalisation might be suggested by economic theory, and Sims' original approach to choosing an orthogonalisation was to impose a causal ordering on the variables in the VAR. However, such a causal ordering can be difficult to justify in practice. In the absence of a generally accepted casual ordering, the orthogonalised impulse responses are difficult to interpret economically.

[8] See, for example, pages 108–109 of Hamilton (1994).

[9] Limiting attention to the fundamental Wold representation is not uncontentious. As shown in Hansen and Sargent (1991), for example, the MA representation that underlies the VAR model can be non-fundamental (in the sense that one or more of the roots of the MA process fall inside the unit circle) and at the same time be economically meaningful.

Due to their flexibility and ease of use, VAR models are used extensively in forecasting and as benchmarks for evaluation of large-scale and DSGE models. In order to mitigate the curse of dimensionality and the large number of parameters typically estimated in VAR models, Doan, Litterman and Sims (1984) have also proposed Bayesian VARs (BVARs) which combine unrestricted VARs with Bayesian, or what has come to be known as 'Minnesota' priors. Other types of priors have also been considered in the literature; DeJong *et al.* (1993), for example, combine a VAR(1) model with prior probabilities on its parameters derived from a RBC model. This approach represents a coherent attempt to take advantage of the empirical simplicity of the VAR approach while at the same time making use of economic theory and, as discussed later in this chapter, is an approach which has been taken up recently in the context of Dynamic Stochastic General Equilibrium modelling. See also Section 2.3 on the use of Bayesian techniques in DSGE models.

### 2.2.2 *Structural VARs*

The structural VAR approach builds on Sims' approach but attempts to identify the impulse responses by imposing *a priori* restrictions on the covariance matrix of the structural errors and/or on long-run impulse responses themselves. This approach is developed by Bernanke (1986), Blanchard and Watson (1986) and Sims (1986) who considered *a priori* restrictions on contemporaneous effects of shocks, and subsequently by Blanchard and Quah (1989), Clarida and Gali (1994) and Astley and Garratt (1996) who use restrictions on the long-run impact of shocks to identify the impulse responses. In contrast to the unrestricted VAR approach, structural VARs explicitly attempt to provide some economic rationale behind the covariance restrictions used, and thus aim to avoid the use of arbitrary or implicit identifying restrictions associated with orthogonalised impulse responses. However, while the use of 'theory based' covariance restrictions in small systems allow the impulse responses to be identified under the structural VAR approach, such restrictions still do not enable identification of the long-run relationships among the variables. Furthermore, even the covariance restrictions are not always easy to interpret or motivate from an economic perspective, particularly in the case of VAR models with three or more variables. So, as explained in detail in the following chapters, the number of exactly identifying covariance restrictions required increases rapidly with the number of variables in the VAR. In a system involving $m$ variables and a set of $m$ orthogonalised structural shocks, the required number of such restrictions is equal to $m(m-1)/2$. For example, in the case of the core model of the UK presented in this book, which includes nine endogenous variables, the number of covariance restrictions required to exactly identify the impulse responses will be 36, even if the covariance of the structural shocks is assumed to be diagonal. It is not clear how so many restrictions could be identified within the structural VAR framework, let alone motivated from an appropriate economic theory perspective.





There are also inherent difficulties with the interpretation that are given to the impulse responses obtained under the structural VAR approach. For example, in Blanchard and Quah (1989), a bivariate VAR model of unemployment and output growth is investigated by first solving the two variables in terms of two orthogonalised white-noise shocks, and then estimating impulse responses under the identifying assumption that one of the shocks has no long-run effects on output levels. They then refer to this shock as the 'demand shock', and refer to the other shock as the 'supply shock'.[10] However, while it might be an interesting exercise to consider the effects on output and unemployment of the two different types of shock, and while it might be possible to elaborate a model of the macroeconomy in which demand shocks have the property assumed by Blanchard and Quah, there seems little rationale in referring to these innovations as 'demand' and 'supply' shocks in the context of the purely statistical model used by these authors. The different types of shock considered in this analysis are defined with reference to their statistical properties (*i.e.* whether or not they have a permanent effect on output levels) and not with reference to a model of how consumers and producers behave in a macroeconomy.[11] Also, in the context of VAR models with three or more variables, the possibility of more than one permanent or transitory shock poses a further identification problem since many combinations of stationary shocks will themselves be stationary. For further details see Section 3.2.5.

## 2.3 Dynamic stochastic general equilibrium models

Unrestricted VARs and the Structural VARs make minimal use of economic theory, while the use of theory in large-scale models is typically modular,

[10] Recall that since $m = 2$, only one covariance restriction is needed to identify the impulse responses.

[11] For a more detailed critical evaluation of the structural VAR approach see Levtchenkova *et al.* (1998).

in the sense that the theory is used in a coherent manner only in specific modules or parts of the model. In contrast, the DSGE models develop a general equilibrium approach to modelling using stochastic intertemporal optimisation techniques applied to decision problems of representative households and firms.[12]

The DSGE model is expressed in terms of 'deep' structural parameters, such as the parameters that enter the preferences, production technologies and the probability distributions of taste and technology shocks. In practice, very simple forms are chosen for these functions (power utility function and Cobb–Douglas production functions, for example). Nevertheless, the resultant optimal decision rules are complicated functions of the macroeconomic variables. These are generally approximated around the deterministic steady-state values of the macroeconomic variables to provide a log-linear system of rational expectations (RE) equations with backward and forward components. The RE solution of this system is obtained assuming certain transversality conditions hold (thus ruling out bubble effects), the DSGE model provides the correct characterisation of economy, the representative agent paradigm is acceptable, and that the underlying processes remain stable into the infinite future. The latter assumption is made implicitly (although rarely acknowledged) in order to derive the expected present value of the discounted future variables that enter the RE solution. Under these assumptions the RE solution can be written as a VAR (or a VARX in the case of open economies) model subject to cross-equation parametric restrictions.[13]

The proponents of the DSGE approach to macroeconomic modelling argue that this approach takes macroeconomic theory seriously in a way that the large-scale SEMs do not. In particular, it is argued that the use of a general equilibrium framework ensures that the DSGE models display stock equilibria, rather than the flow equilibria which are characteristic of the traditional approach to macroeconometric models. The derivation of the model's relationships as solutions to intertemporal optimisation problems of households and firms ensures that the model has an internal consistency and a relationship with economic theory that is lost in traditional large-scale models. However, we have already noted that the proponents

[12] For a survey of early developments in the literature on DSGE models, see the contributions in the volume edited by Cooley (1995), while discussion of the more recent 'New Keynesian' DSGE models is given in Smets and Wouters (2003) and Christiano *et al.* (2005).

[13] A specific illustration of this procedure is given in Chapter 3 below. See also, for example, Binder and Pesaran (1995), Kim and Pagan (1995), Wickens (1995), and Pesaran and Smith (2005) in the case of open economy DSGE models within a global context.





of large-scale models have made considerable progress in relating the structure of their models to economic theory, particularly in relation to the long-run properties of the model. Indeed, we noted that there has developed a consensus on the appropriate theory for the characterisation of the long run, based on Walrasian general equilibrium theory, which has been adopted (at least in part) in many of the current generation of large-scale models. In this respect, therefore, the differences in the theoretical underpinnings of the DSGE models and the large-scale models are less polarised than is sometimes argued.

However, there are important differences between the two approaches both in content and in emphasis. In particular, they differ significantly in their treatment of short-run dynamics. The DSGE models not only provide the form of relationships between economic variables that exist in the long run, but also provide an explicit statement of the dynamic evolution of the macroeconomy in response to shocks. It is argued (for example, in Plosser, 1989) that the foundations of typical Keynesian models are static in nature, and that the dynamics are introduced arbitrarily through accelerator mechanisms for investment and inventory behaviour, or through arbitrary nominal rigidities in wage and price setting, or through partial adjustment mechanisms in various forms, for example. The lack of cohesion in the derivation of the long-run and dynamic properties in the large-scale models represents a fundamental shortcoming of the large-scale SEMs, according to this argument, encouraging the view that the long-run evolution of the macroeconomy can be considered independently of short- and medium-term fluctuations. In contrast, there are no dichotomies between the determinants of long-run growth and short-run fluctuations in DGSE models (though the long run is often not modelled explicitly in its entirety in DSGE models either and actual data are often (arbitrarily) filtered before they are analysed).

In fact, one can distinguish two phases in the development of the DSGE models which have separate implications for modelling macrodynamics. In the first phase, one of the primary motivating ambitions behind the DSGE models was to establish that the dynamic responses of the macroeconomy are consistent with a model in which there are no market failures, the predicted outcomes are Pareto optimal, and intervention by a social planner to force agents to change their actions will be welfare reducing. The 'real business cycle' agenda that lay behind the first phase of the development of the DSGE approach to modelling therefore played down the potential role of monetary policy in generating economic fluctuations and instead placed considerable emphasis on real shocks. Indeed, many of the calibration exercises undertaken in the first phase of the DSGE literature ignored the monetary sector altogether.

It was quickly recognised that this first phase of models required some refinement if it was to provide a satisfactory understanding of economic fluctuations. The first generation of DSGE models were therefore extended to incorporate features such as adjustment costs (*e.g.* Kydland and Prescott, 1982, Christiano and Eichenbaum, 1992a, and Cogley and Nason, 1995); signal extraction and learning (*e.g.* Kydland and Prescott, 1982, and Cooley and Hansen, 1995); aggregation (*e.g.* Christiano, Eichenbaum and Marshall, 1991 on temporal aggregation and Cooley *et al.* 1997 and Ríos-Rull, 1995 on cross-sectional aggregation); endogenous technological progress (*e.g.* Stadler, 1990 and Hercowitz and Sampson, 1991) and information heterogeneities (*e.g.* Kasa, 2000). However, it remained unclear whether a model could be developed that would be capable of simultaneously dealing with all of these factors in a satisfactory manner and, even if it could, whether it would be any more transparent or easy to interpret than the available stock of large-scale models. Moreover, by limiting attention to particular sources of dynamics, the first-phase models following the DSGE approach were likely to be too restrictive. In fact, as it turned out, when the models were confronted with the data, in Litterman and Weiss (1985), King *et al.* (1991), Christiano and Eichenbaum (1992b) or Kim and Pagan (1995), for example, the evidence suggested that this was indeed the case.

The second phase in the development of DSGE models returned to the simpler basic characteristics of the earliest DSGE models, emphasising the micro-foundations of macroeconomic fluctuations, but explicitly incorporating nominal frictions and paying more attention to monetary factors influencing business cycles. There were early attempts to incorporate money in DSGE models (see, for example, Cooley and Hansen, 1989, 1995), but there is now a considerable literature elaborating 'New Keynesian DSGE models', which have price and wage rigidities at their core and which are designed to consider the impact of monetary policy (see Clarida *et al.* (1999) for a review). A simple New Keynesian DSGE model consists of an 'IS curve' relating output to the expected real interest rate, a Phillips curve relating inflation to expected inflation and output (measured as deviations from its trend), and a policy rule relating the nominal interest rate to output and inflation. The IS curve is motivated with reference to optimising behaviour on the part of households, the Phillips curve is based on profit-maximising pricing behaviour on the part of monopolistically competitive firms, and the policy rule is based on a policy-maker that optimises an objective function describing welfare in terms of inflation





and output.[14] As in all DSGE models, the decisions made by households, firms and the policy-maker are interrelated and intertemporal, generating explicit dynamic structures. But this class of models also pays particular attention to the rigidities that exist in price setting, frequently incorporating 'Calvo (1983) contracts', in which prices are reset only periodically and with a fixed probability, to motivate both backward- and forward-looking effects in the Phillips curve, for example. These modelling assumptions have important implications for the dynamic properties of the DSGE models, their ability to fit the data and their implications for monetary policy analysis. Indeed, recent modelling exercises by Gali and Gertler (1999), Clarida *et al.* (2000), Smets and Wouters (2003), Favero and Rovelli (2003), Del Negro and Schorfheide (2004), Del Negro *et al.* (2005) and Christiano *et al.* (2005), among others, indicate that these second-generation DSGE models are able to introduce more flexible dynamics, often with the help of Bayesian estimation techniques, and can perform relatively well in explaining various episodes of historical macroexperience and in forecasting.

## 2.4 The structural cointegrating VAR approach

The structural cointegrating VAR modelling strategy is described in detail in Section 3.1.3 of the next chapter. But, stated briefly, the strategy begins with an explicit statement of the long-run relationships between the variables of the model obtained from macroeconomic theory. These relationships will typically be based on stock-flow and accounting identities, arbitrage (equilibrium) conditions, and long-run solvency requirements that ensure stationary asset–income ratios. The long-run relationships are approximated by log-linear equations, with disturbances that characterise the deviations of the long-run relations from their realised, short-run counterparts. These deviations are referred to as the 'long-run structural shocks'. Not all of the variables contained in the long-run relationships suggested by economic theory are observable, however, and in writing the long-run relationships in terms of observable variables, 'long-run reduced form shocks' are derived as functions of the long-run structural shocks. The long-run, or error correcting, relations are then embedded within an otherwise unrestricted log-linear VAR model of a given order in the

[14] For an open economy version of the New Keynesian DSGE model see, for example, Gali and Monacelli (2005).

variables of interest to obtain a cointegrating VAR model which incorporates the structural long-run relationships as its steady-state solution. This allows testing for the presence of the cointegrating relations and the over-identifying restrictions implied by the long-run economic theory. In this way, the cointegrating VAR model will embody the long-run theory restrictions in a transparent, and an empirically consistent, manner. The theory also imposes restrictions on the intercepts and/or the trend coefficients in the VAR, which play an important role in testing for cointegration as well as co-trending, often ignored in other approaches to macroeconometric modelling.[15]

### 2.4.1 *Comparisons with the alternative approaches*

#### COMPARISON WITH LARGE-SCALE SEMS

As the discussion above makes clear, the structural cointegrating VAR approach to macroeconometric modelling begins by describing the relationships which define the long-run structure of the macroeconomy, and embeds these long-run relationships within an otherwise unrestricted VAR model of the macroeconomy. The number of variables chosen to include in the core model is selected to ensure that the system can be estimated simultaneously, taking into account all of the potential feedbacks between the variables captured by the short-run dynamics and suggested by the long-run economic relationships. One of the primary strengths of this approach, therefore, is that the model is developed and estimated in a way that ensures that the long-run relations of the estimated model are data consistent and theoretically coherent. Furthermore, this is accomplished without compromising short-run empirical adequacy as an important criteria by which models in the final analysis must be judged. The transparency of the model's long-run properties would also be important for impulse response analysis and forecasting, particularly over the medium term.

Despite its advantages, the cointegrating VAR model is still highly restrictive and, given the available time series data, it can deal with at most 8–10 variables simultaneously. This clearly precludes addressing many important issues if we were to confine our analysis to a single cointegrating VAR model. Macroeconometric models are used for many different purposes by government, academic and corporate institutions, and no one

[15] See Chapter 6 for a discussion of the relevant econometric issues involved in the analysis of cointegrating VARs.





model will be appropriate for all of these uses (see Whitley, 1997). However, traditional macroeconometric models tend to become large often in response to demands for more disaggregated analysis, and for addressing a wider range of policy questions. For example, a central bank may require a detailed model of the monetary sector, corporate institutions might require forecasts and analysis disaggregated by the main industrial sectors (energy, construction, agriculture, transportation, *etc.*), and government agencies might be required to investigate the effects of a given policy on particular interest groups and/or markets. As will be discussed in more detail in Chapter 3 below, our approach to meeting these model-specific requirements is through the development of appropriate *satellite* models. These are constructed using similar econometric techniques to those employed in the estimation of the core model, and are then linked up to the core model, with the core variables (and the associated error correction terms from the core model) influencing sectoral developments, but not *vice versa* (see Pesaran and Ron Smith, 1997). The distinction between the core and satellite models is made possible by allowing the error correction terms of the core model to enter the relationships of the satellite models but not *vice versa*. This enables consistent estimation of the satellite model by treating the variables of the core model as weakly exogenous. Examples of satellite models include models of the labour market, households' portfolio and expenditure decisions, foreign trade and fiscal policy.[16]

#### COMPARISON WITH UNRESTRICTED AND STRUCTURAL VAR MODELLING

Unrestricted and restricted VAR modelling places great emphasis on characterising the dynamic behaviour of variables and makes considerable use of impulse response analysis as a means of illustrating the timing of the reactions of various variables to different types of structural shock. The identification of the structural shocks, using the reduced form shocks obtained from the estimated VAR models, requires a well-defined economic theory of the short run, concerned with the sequencing of decisions and information available to different economic agents and with the various rigidities arising in decision-making. This emphasis on identifying the effects of specific economic shocks and the associated short-run dynamics contrasts with that of the structural cointegrating VAR approach.

[16] An illustration of how a satellite model of the household sector might be coupled with the core macroeconomic model is described in Chapter 12.

The structural cointegrating VAR approach to modelling emphasises the long-run relationships that exist between variables. This is based on the view that economic theory is typically more informative on these long-run relationships than it is on the short-run dynamics, noting that theory is frequently silent on the sequencing of decisions, the structure of information sets across agents, and the nature of rigidities that arise from transactions costs. The structural cointegrating VAR approach describes explicitly the nature of the '*long-run* structural errors' that arise from a specific economic theory and that characterise deviations from long-run relationships. It also clarifies the links between these long-run structural errors and the 'long-run reduced form errors' that can be related to the data at hand.

If it is the case that economic theory is insufficiently well-defined to provide credible identifying restrictions on the short-run behaviour of economic agents, then a more general method of analysing impulse responses is required; that is, one that allows an examination of the short-run dynamic interrelations of the model without needing to identify the nature of the shocks. The current literature on impulse response analysis focuses on the effects of identified shocks are often difficult to accomplish in a satisfactory manner, particularly in the case of VAR models with 8–10 variables often encountered in the analysis of small open economies. The source of the difficulty lies in the *unobservable* nature of the shocks of interest such as monetary policy shocks, say, or demand and supply shocks. An alternative, less ambitious approach is to consider the impulse response functions associated with unit shifts in observable variables, such as output, interest rates and inflation. Clearly, a unit shock to the interest rate variable need not be the same as a monetary policy shock, since many different internal and external factors could influence interest rates. But the impulse response associated with a unit (one standard error) shift in interest rates would be informative about the dynamic properties of the model as well as being relevant to private sector decisions that are concerned with the consequences of a rate rise rather than the precise reasons behind its occurrence. The Generalised Impulse Response Function (GIRF), introduced in Koop *et al.* (1996) and developed in Pesaran and Shin (1998), provides such a method. Unlike the more familiar orthogonalised IR functions, the GIRFs are invariant to the ordering of the variables included in the VAR and provide an empirically coherent solution to the analysis of impulse responses so long as the shocks under consideration relate to observed variables. For example the GIRFs can be used to compute the time profile of the effects of a shock to oil prices, output or interest rate without any ambiguities. In many applications, such as the analysis of market interactions or the sensitivity of market or credit risks to changes in the market environment, the GIRFs are sufficient. The effects of system-wide shocks on the variables of the VAR or on the cointegrating relations can also be analysed using the persistence profile methodology advanced in Pesaran and Shin (1996). This type of analysis is also invariant to the ordering of the variables in the VAR and does not require economic identification of the shocks. The identification problem arises when it is further required to decompose the effects of the shocks to the observed variables into unobserved theoretical concepts such as supply, demand, or monetary policy shocks. In such cases, as we shall demonstrate in Chapter 10, the GIRF approach need to be combined with additional *a priori* restrictions from economic theory, preferably within a decision context.[17]





It is worth emphasising that the structural cointegrating VAR approach to modelling is not incompatible with the identification of economically meaningful shocks to the macroeconomy and the application of more standard impulse response analysis. Rather, this is a question of emphasis. The structural cointegrating VAR approach implies that the structural relationships that are suggested by theory for the short run are less robust and can be held with less confidence. But it is perfectly possible to elaborate an economic theory which motivates both short-run and long-run restrictions and the structural cointegrating VAR approach would remain valid (supplemented with the additional restrictions suggested on the short run). These issues are discussed in detail in Chapter 3 below, which concentrates on the identification issues associated with short-run structures, and in Chapter 5, where a specific model of short-run decision-making is elaborated to illustrate the issues involved in showing how monetary policy shocks can be identified without having to identify other types of shocks that might also impinge on the macroeconomy.

## COMPARISON WITH DSGE MODELLING

In DSGE modelling, the derivation of the long-run, steady-state relations of the macromodel starts with the intertemporal optimisation problems faced by households and firms and then solves for the long-run relations using the Euler first-order conditions and the stock-flow constraints. Given the invariably non-linear nature of the Euler equations and the linear forms

[17] The econometric issues involved in GIR analysis are discussed in Chapter 6 and their application to the core model of the UK economy is described in Chapter 10.

of the constraints, the resultant relations of the model economy are usually approximated by log-linear relations (the real business cycle literature and the New Keynesian DSGE literature follow this methodology). The long-run relations are then obtained by assuming that the model economy is stationary and ergodic in certain variables, such as growth rates, capital per effective worker and asset–income ratios, and typically ignoring expectational errors. The structural cointegrating VAR approach, on the other hand, works directly with the arbitrage conditions which provide intertemporal links between prices and asset returns in the economy as a whole. The arbitrage conditions, however, must be appropriately modified to allow for the risks associated with market uncertainties.

Clearly, the above two approaches are closely related and yield similar results as far as the long-run relations are concerned. The main difference between the two approaches lies in the empirical validation of the long-run relations and their treatment of short-run dynamics. The strength of the intertemporal optimisation approach lies in the explicit identification of macroeconomic disturbances as shocks to tastes, to technology, to policy, and so on, rendered possible by the explicit statement on the form of the short-run dynamics. However, this is achieved at the expense of often strong assumptions concerning the form of the underlying utility and cost functions, expectations formation process and the related assumption that the DSGE model remains stable into the indefinite future, and the process of technological change. In contrast, the cointegrating VAR approach advanced in this work is silent on short-run dynamics, but is in line with the DSGE model as far as the long-run relations are concerned. Our approach also has the added advantage that particular long-run relations are considered only when adequately supported by the evidence. We test the validity of the long-run relations rather simply imposing them on *a priori* grounds.

Both the DSGE modelling approach and the structural cointegrating VAR approach represent attempts to combine theory and evidence to obtain models that will be useful for policy- and decision-makers. The differences in approach reflect modellers' strength of conviction on different aspects of the theory and evidence. So, the structural cointegrating VAR approach assumes that we understand how the economy works in the long run with some degree of confidence, and allows theory to inform this aspect of modelling. But it is less sure on the short-run dynamics and so turns to the evidence on these. In comparison, the DSGE approach emphasises more the use of theory in the modelling of both the short run and long run.





We shall show, in Chapter 6, that the estimation of our structural cointegrating VAR model is straightforward using estimation techniques developed in Pesaran and Shin (2002) and Pesaran, Shin and Smith (2000). The issue of combining theory and evidence is typically less straightforward in the larger DSGE models where the highly restricted VAR model suggested by the theory cannot be readily reconciled with the data. Kapetanios *et al.* (2005) discuss this issue, outlining the steps taken in the construction of a 'conceptual model' (for example, a restricted VAR derived from a variant of a DSGE model) and its translation into a 'data adjusted model' which can better match the data in policy-oriented macroeconomic modelling. One approach to making this translation is Ireland's (2004) method based on 'tracking shocks'. Here, any observed macroeconomic variable is assumed to differ from its corresponding latent variable (as generated by the conceptual model) by a tracking shock. This shock, in turn, is assumed to follow some known stochastic process. Forecasts are provided as an average reconciliation of the data and the outcome suggested by the conceptual model, with the split between theory and evidence depending on the nature of the tracking errors in the sample.[18] Alternatively, Del Negro and Schorfheide (2004) describe a Bayesian method, along similar lines to that developed by DeJong *et al.* (1993), in which a New Keynesian DSGE is used to provide priors for a VAR and these are updated in the light of the data, where the investigator explicitly chooses the weight to be placed on the theory-based prior relative to the evidence. The paper also shows how the posterior inference on the VAR parameters can be translated into posterior inference for the DSGE parameters so that theory and evidence is combined and summarised in such a way as to retain its economic meaning. A third possible method, advocated by Christiano *et al.* (2005), focuses on matching theoretical and empirical impulse responses.

Kapetanios *et al.* (2005) make the important point that, no matter which method is used to combine theory and evidence, the underlying conceptual model will need to accommodate cointegrating relations if the effects of some shocks are persistent (so that some of the variables are $I(1)$ variables and long-run relations exist between them in levels). This feature will provide its own restrictions on the VAR derived from the conceptual model so that, once the theory-based long-run relations are incorporated

[18] Recent models in various central banks adopt a DSGE structure as their core theoretical components, but also allow for non-core empirically based dynamics. See, for example, the TOTEM model of the Bank of Canada as described in Cayen, Corbett and Perrier (2005) or Adolfson *et al.*'s (2005) description of their model of the Swedish economy.

into the model, it can be written as a VECM (see also Giannone *et al.* (2005)). They note that failing to impose these restrictions (if cointegration exists in the data) will cause difficulties when trying to match the theory with data and will cause considerable problems in forecasting.[19] A related issue arises in many DSGE models in which analysis is carried out using variables measured as deviations from some *ad hoc* trend estimate (*e.g.* the Hodrick–Prescott filter). Of course, the choice of a misspecified trend will generate bias in estimation so the choice of trend is much more significant than many DSGE modellers are prepared to acknowledge. But perhaps even more importantly, the use of this type of de-trending makes it rather difficult to test hypotheses based on long-run theory. In contrast, our approach readily allows the long-run theory to be tested and the equilibrium values to be explicitly identified.

The long-run structural and the DSGE approaches both represent attempts to reconcile theory and data. The differences between the approaches are based on differences in emphasis and practicalities rather than principle. The methods taken in the DSGE models to reconcile theory and data oblige the projected paths of the variable to converge to the equilibrium value suggested by the theory of the core conceptual model. This implicitly places emphasis on the long-run properties of the theory, which are held with some confidence, exactly as in our approach. But this is achieved in a more restricted way than in our long-run structural approach (being based on a single weighting parameter in the Bayesian method described above, for example) and the long-run relations suggested by theory are typically not tested in the DSGE models. The short-run restrictions suggested by the DSGE models (including those implied by the forward-looking expectations involved[20]) can be accommodated, and tested, within the cointegrating VAR framework used in the long-run structural approach.

In short, many economists might accept the view that economic theory is more likely to provide a coherent guide to the long-run characteristics of the macroeconomy than its short-run dynamics, and the mainstream macroeconometric and structural VAR models are based on a pragmatic approach to capturing the dynamics. As we shall demonstrate in the

[19] Christiano, Eichenbaum and Evans's (2005) attempts to tie down model parameters by matching impulse responses will suffer from this shortcoming, for example, since the impulse responses are based on short-run dynamics and are not consistent with the presence of long-run relations in levels.

[20] See Section 3.2 for details on how the expectation effects are accommodated in the long-run structural model.





following chapter, our own approach is to allow the dynamics to be flexibly estimated within a VAR or VARX framework, but to impose restrictions on the system to ensure that the estimated relationships are theory-consistent in the long run. Theory-inspired short-run restrictions can then be considered in the light of their empirical validity, and not adopted blindly since they are implied by a particular macroeconomic theory.