# Structural Modelling of the UK Economy within a VAR Framework using Quarterly and Monthly Data

## Summary of Aims and Objectives

1. To estimate a small quarterly macroeconomic model of the UK, based on a VAR model of a number of 'core' macroeconomic variables, and employing recently developed econometric techniques to test and impose restrictions on the long run relationships of the model. Also, to analyse the short run dynamic properties of the model and to investigate the role of exogenous variables, all with a view to analysing specific aspects of the way in which the UK macroeconomy functions.
2. To evaluate a limited number of economic theories within the context of a small but complete macromodel.
3. To construct a monthly model of the UK economy corresponding as far as possible to the quarterly model.
4. To undertake some policy evaluation exercises, and to investigate the sources of shocks which generate fluctuations in real and nominal macro-variables in the UK economy and the mechanisms by which the effects of different shocks are propagated across different macroeconomic variables and over time.

## Significant achievements

The project has made significant contributions to all areas under the original aims and objectives of the project listed above. It has:

1. developed new econometric techniques for long run structural modelling (Pesaran, Shin and Smith 1999a,b) and for impulse response analysis (Koop, Pesaran and Potter, 1996, Pesaran and Shin, 1996, 1998) which have already become established in the literature;
2. produced a theory and data consistent small quarterly macro model of the UK economy (Garratt *et al.* 1998, 1999a,b);
3. produced a monthly equivalent of the quarterly model in Weale (1999) and this has been compared directly with the quarterly model. The comparison has highlighted the potential use of monthly data, where the monthly interpolands are now regularly used for publishing monthly estimates of GDP, as a useful addition to quarterly data; and
4. applied the quarterly model to a range of policy questions (Garratt *et al.* 1998, 1999a,b). A significant application of the model is its use in the analysis of the short run dynamics of the macroeconomy and the speed of movement back towards long run equilibrium. This application could turn out to be helpful in the timing and conduct of macroeconomic policy. We are also using the UK model for probability forecasting. This should improve the understanding and usefulness of forecasts based on macroeconomic models and should complement the activities currently undertaken by the Bank of England (and others). Both applications represent important innovations in the use of cointegrating VAR models in the context of a small open economy.

**Summary of Research and Results**

Over the past two decades, there has been a growing interest in developing macroeconomic models with transparent theoretical foundations and flexible dynamics that fit the historical time series data reasonably well. The modelling framework developed and implemented in this research project, along with the work of King *et al*. (1991) and Mellander *et al*. (1992), represent the first steps towards this aim. The research of the project can be conveniently grouped into four main areas. *First*, we have developed new econometric techniques for use in the analysis of cointegrating VAR models. *Second*, we have applied these in the construction of a quarterly model of the UK economy. *Third*, we have compared this model with an equivalent model constructed on the basis of monthly data. And *fourth*, we have employed the models in the analysis of a number of policy-related issues.

The research of the project has made important contributions to the econometric analysis of cointegrating VARs. The methods developed on the project enable us to impose and test the validity of restrictions on the long run properties of a cointegrating VAR model without imposing restrictions on its short run dynamics. In addition to developing the techniques required to investigate these issues, the econometric methods have drawn attention to the role of economic theory in modelling work because the approach to macroeconomic modelling places primacy on the long-run relationships that exist between variables as suggested by economic theory. The work on long-run structural modelling describes an approach for time-series modelling in cointegrating VAR models (and develops the techniques necessary to implement this approach) which we hope will be widely adopted in applied econometric research.

The main focus of the empirical part of the research has been the construction of a quarterly model of the UK economy. Under the project, we have developed a long-run framework suitable for modelling a small open macroeconomy like the UK. The model contains transparent and theoretically coherent long-run properties of the type exhibited by Real Business Cycle models. The long-run relations are derived rigorously from production, trade, arbitrage, solvency and portfolio balance conditions, and these are then embedded in an otherwise unrestricted VAR model. The model comprises five domestic variables whose developments are widely regarded as essential to a basic understanding of the behaviour of the UK macroeconomy; namely, aggregate output, the relative domestic price level (relative to oil prices), the nominal interest rate, the exchange rate and real money balances. The model also contains foreign output, foreign interest rates and a foreign price variable measured once again relative to oil prices. We have developed a new strategy which provides a practical approach to incorporating the long-run structural relationships suggested by economic theory in an otherwise unrestricted VAR model. The description of the modelling work provides one of the first examples of the use of the econometric techniques that have been developed on the project in an applied context.

The project has also considered the use of monthly data in macroeconomic modelling. In particular, we have: (i) developed techniques for producing monthly interpolands of quarterly data to the point where they are in regular use for publishing monthly estimates of GDP; (ii) assessed maximum-likelihood methods of using interpolated data taking account of the fact that interpolated data are affected by measurement error; (iii) developed methods of comparing monthly and corresponding quarterly models; and (iv) estimated a monthly version of the quarterly model. We have concluded that the main function of monthly data and monthly models is to build up a picture of the current quarter for use in decision-making concerned with the very short run. Even with one month's hard data, it is typically possible to produce an estimate of the position in the current quarter better than that given by the fitted value of a quarterly model. On the other hand, the quarterly model seems to do better outside the current quarter and is more appropriate for decision-making over longer horizons therefore.

The empirical analysis of the project provides insights on the UK macroeconomy which should be useful both in understanding the functioning of the macroeconomy and in the timing and conduct of macroeconomic policy. For example, the econometric methodology that has been developed provides the means for testing formally the validity of (over identifying) restrictions implied by specific long-run structural relations without imposing 'incredible' restrictions on the short-run coefficients. 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 macro theories. The economic theory, and the statistical considerations for the empirical application, suggest that there are five long-run cointegrating relationships among the eight core variables of the macro-model, and the statistical tests provided little evidence with which to reject this view. Under the assumption that there are indeed five long-run relationships, we obtained a model in which the freely-estimated parameters take sensible signs and are of plausible orders of magnitude. The relationships of the model include the Interest Rate Parity relationship, a modified Purchasing Power Parity relationship, a relationship between domestic and foreign outputs, a trade balance relationship and a real money balance relationship. Further, we tested for the validity of fourteen (over-identifying) restrictions, eleven of which were intrinsic to the theory, and three of which were consistent with the theory and were included for reasons of parsimony. Using small sample adjusted likelihood ratio tests, we were not able to reject these over-identifying restrictions, and from this we conclude that the estimated model is both theory and data consistent.

A second important area of application for the model is in the analysis of the dynamic response of the macroeconomy as it reacts to new events, focusing on the contribution of the embedded long-run relationships to these dynamics. To this end, we compare the statistical performance of the model with a benchmark model which omits the long-run relationships. We also present Persistence Profiles based on our estimated model which illustrate the speed with which disequilibria in the various long-run relationships are eliminated. For example, the estimated profiles illustrate clearly the differential speeds of response to the disequilibria involving financial variables (e.g. differentials in UK and foreign interest rates, in which 80% of adjustment takes six quarters to complete) compared to those involving real magnitudes (e.g. the output gap relationship, in which 80% of the adjustment takes two and a half years to complete). The model's ability to capture short-run dynamics, combined with its long-run consistency with a clearly-defined economic model, render it a useful tool for generating interpretable forecasts over the short and medium term. To this end, we have also generated probability event forecasts with respect to inflation, interest rates and output growth over short, medium and long term horizons. We believe that our modelling approach is particularly suited to this purpose and hope that this work should improve the usefulness and transparency of forecasts based on macroeconomic models to complement the activities currently undertaken by the Bank of England (and others).

**Full Report**

## 1. Background

Macroeconometric modelling in the UK and elsewhere has undergone a number of important changes during the past two decades, largely in response to developments in economic and econometric theory as well as to 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. In contrast, 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. 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.

Following these developments, the alternative approaches to macroeconometric modelling in the UK and elsewhere can be grouped under four broad categories. *First*, there are large-scale macroeconometric models such as the HM Treasury's model of the UK economy, and the Federal Reserve Boards model of the US economy. Although these models have made many important innovations, by their very nature they have been slow to evolve. They essentially follow 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 are typically estimated by least squares or by instrumental variables methods, and full information estimation of the model parameters is rarely attempted.

*Secondly*, following the methodology developed by Doan, Litterman and Sims (1984) and Litterman (1986), there are unrestricted, Bayesian, and structural VARs. These are frequently employed for forecasting but are of limited use in policy evaluation.[1] The structural VAR approach aims to provide the VAR framework with structural content through the imposition of restrictions on the covariance structure of various shocks.[2] However, this approach is typically employed to carry out impulse response analysis in a 'structurally' meaningful manner, and does not attempt to model the structure of the economy in the form of specific behavioural relationships.

The *third* approach is closely associated with the Dynamic Stochastic General Equilibrium (DSGE) methodology employed in the Real Business Cycle literature. This approach developed following the seminal work of Kydland and Prescott (1982) and Long and Plosser (1983) provides an explicit intertemporal general equilibrium model of the economy based on optimising decisions of households and firms. Originally, the emphasis of these models was on

[1] See, for example, Cooley and LeRoy (1985).
[2] This approach has been used, for example, by Blanchard and Quah (1989).

real factors (e.g. productivity shocks), but more recently the DGSE models have been extended in a number of directions aimed at allowing for nominal effects, adjustment costs, heterogeneity, and endogenous technological progress, for example. In consequence, the differences between the DGSE and the traditional macroeconometric models have become less pronounced. Also many of the DGSE models can be approximated by restricted VAR models, which brings them more in line with other modelling approaches.[3]

The *fourth* approach, and the one that we have developed in the course of this research project, is the 'structural cointegrating VAR' approach. This approach is based on the desire to develop a macroeconometric model which has transparent theoretical foundations, providing insights on the behavioural relationships which underlie the functioning of the macroeconomy, and which has flexible dynamics that fit the historical time series data well. The structural cointegrating VAR modelling strategy begins with an explicit statement of the long-run relationships between the variables of the model obtained from macroeconomic theory. The long-run relationships are approximated by log-linear equations which include 'long-run structural' disturbances that characterise the deviations of the long-run relations from their realised short-run counterparts. The observable shocks associated with the (often unobservable) long-run structural disturbances are then embedded within an otherwise unrestricted log-linear VAR model. This provides a cointegrating VAR model that incorporates the structural long-run relationships as its steady-state solution. The model embodies the long-run theory restrictions in a transparent manner, including restrictions on the trends and intercepts in the VAR model. On the other hand, the only restrictions placed on the short-run dynamics of the estimated structural model of the macroeconomy are those imposed through the choice of the lag order of the VAR model. Additional restrictions can be placed on these short-run restrictions if an explicitly-formulated model of the short-run is described and used alongside the theory of the long-run. But the modelling approach emphasises the use of long-run theory restrictions, noting that long-run theory does not necessarily contribute to a theory of short-run dynamics and that the theory of the long-run is typically less controversial than that concerned with explaining the short-run dynamics of the macroeconomy.

In what follows, we describe in a little more detail the elements of the project which have enabled us to pursue the long run structural VAR modelling approach in the construction of a quarterly and a monthly model of the UK economy. The discussion of Section 2.1 below focuses first on the methodological contribution of the project. A more detailed description of the estimated quarterly model is described in the Section 2.2, and the applications of the model in described in Section 2.3. Section 3 concludes. A more complete description of the work is provided in the referenced papers produced on the project and, especially, the monograph written by Garratt *et al*. (2000).

## 2. Results

### *2.1 The development of econometric methods*

#### 2.1.1 Long-run structural modelling

One of the most important outputs of the project has been the development of the econometric methods underlying the long-run structural VAR approach to modelling. This approach to modelling has been developed in Pesaran and Shin (1999b) and Pesaran, Shin and Smith (1999a). It is based on a modified and generalised version of Johansen's (1991,1995) maximum likelihood approach to the problem of estimation and hypothesis testing in the context of vector autoregressive error correction models. The first paper, Pesaran and Shin (1999b), develops a

[3] See, for example, Kim and Pagan (1995) and Christiano, Eichenbaum and Evans (1998).

general framework for identification, estimation and hypothesis testing in cointegrated systems when the cointegrating vectors are subject to general non-linear restrictions, obtained from economic theory or other relevant a priori information. It provides a proof of the consistency of the Maximum Likelihood estimators, and establishes their asymptotic distributional properties. This work generalises the results obtained by Johansen and Phillips for the linear case.

The second paper, Pesaran , Shin and Smith (PSS) (1999a), presents two further generalisations of the cointegration analysis in the context of the vector error correction model (VECM). First, a subsystem approach is developed in which a subset of variables can be regarded as structurally exogenous. This means that the cointegrating vectors do not appear in the subsystem VECM for these exogenous variables and the error terms in this sub-system are uncorrelated with those in the rest of the system. In developing these methods, care is taken to adequately take into account the effects of the presence of an intercept or linear trend in the cointegrating relationships (and tests are developed with which to investigate this possibility). The generalisation of the cointegration analysis to the case where there are exogenous I(1) variables is of widespread use, and is particularly relevant for our macroeconometric analysis of 'small open' economies where it is plausible to assume that some of the foreign I(1) forcing variables may be viewed as exogenous. And the appropriate treatment of trends and intercepts in the cointegrating relationships is essential if the estimated model is to adequately reflect economic theory. Second, PSS consider the case in which the lag lengths of the included variables may differ within and between equations. This extension is also important in applied contexts where, due to data limitations, the researchers may wish to use a priori restrictions or model selection criteria to choose lag orders of the stationary variables in the model.

The development of the econometric methods in the work described above has been central to the development of the project's programme of work, but additional research results have also arisen as a direct consequence of the work of the project. Specifically, the econometric methods developed above place considerable emphasis on the role of economic theory in modelling work and, in particular, emphasise the importance of the long-run economic theory in modelling work. These arguments are developed in detail in Pesaran (1997) and Pesaran and Smith (1997, 1998), while further econometric methods designed to investigate the effects of the presence of long run relationships in time series models have been obtained in Pesaran and Shin (1999a) and Pesaran, Shin and Smith (1999b). The emphasis placed on the role of the economic theory of the long-run is based on the view that, typically, such theory is less contentious than the economic theory of the short-run. This is not to say that we are uninterested in the short-run dynamic properties of VAR models, however, and during the course of the project we have made a number of contributions to the analysis of the dynamics of cointegrating VAR models. For example, we have developed methods for considering the stability of a cointegrating VAR (described in Garratt *et al.*, 2000); we have discussed the problems of addressing the short-run identification problem and the approaches advanced in the literature (in Garratt *et al*., 1998, 2000); and we have developed further our work on the analysis of short run dynamics in the absence of short-run identifying restrictions through Generalised Impulse Response (GIR) analysis and Persistence Profiles [PP] (in Pesaran and Shin, 1998).

### 2.1.2 Monthly Interpolation

The project has also made considerable progress in the development of techniques related to the use of monthly data in macroeconomic modelling. The main problem to be surmounted in constructing monthly models is the fact that the national accounts aggregates are published only quarterly. There are two possible solutions to this. One solution, adopted by Artis *et al*. (1995) among others, is to use the published monthly data. Hence, for example, available data on industrial production might be used as a 'proxy' for GDP. However, these cover only 28% of the economy and are not helpful if the monthly model is to relate to the whole economy. Moreover, if the proxy is used for GDP, then this is likely to create a substantial errors in variables problem

which would need to be addressed. The alternative solution, and the one pursued by Weale and Salazar at the National Institute as part of this project, is to develop methods to interpolate quarterly data to give the necessary variables on a monthly basis.[4] This procedure allows us to produce a monthly model with the same structure as the corresponding quarterly model and then to compare the performance of the two models. In turn this has allowed us to draw important conclusions about the role of monthly data in economic modelling and policy work.

To describe the work in a little more detail, the data are calculated using interpolation methods to fill in and project forward the output components of GDP at basic prices. The estimates are produced at the same time as the ONS publishes its industrial production figures: i.e. an estimate for May is published at the start of July. Taken on their own, it would not be easy to assess the performance of the data and thus of the underlying model. However, the National Institute uses VAR models to project the indicator variables forward by a month and this allows us to produce a forecast of monthly GDP for the month which has just finished. In turn , this means that we can produce an estimate of quarterly GDP about 3 weeks ahead of the ONS first estimate. A comparison of our estimates with the first estimates of the ONS provides reassurance that our approach is useful. A Monte-Carlo study of our interpolation method suggested that there would be a standard error of about 0.1% point in the interpolated figure for the output of market services.

Estimation using these (or any) interpolated data has to take account of the fact that interpolation has errors associated with it. The interpolation method we use allows us to work out the covariance matrix of these measurement errors and we have developed estimation techniques which use this information as a means of taking into account the measurement error. One method of estimation is maximum likelihood, where the likelihood function of the observed data is written in a form which has the measurement (interpolation) error and the behavioural errors independent of each other. Salazar and Weale (1999) applied this method to a bivariate monthly VAR of GDP growth and RPI inflation with no exogenous variables. However, the solution involves the repeated manipulation of matrices of dimension equal to the number of observations multiplied by the number of variables in the model. This makes it at present impractical as a tool for estimating larger models over any reasonable time period. A second estimation method is the standard errors in variables model presented by Fuller (1987). Since the same variables appear in all the equations, the method can be applied equation by equation to the system as a whole to obtain a consistent estimator of the GLS estimator. This second method neglects the interaction between the model coefficients and the measurement error but provides a more practical alternative for reasonably sized models.

### *2.2 The long-run structural VAR model of the UK economy*

The primary aim of the project has been, of course, to construct a quarterly long-run structural VAR model of the UK economy. This activity has been described in detail in Garratt *et al*. (1998, 1999a, 2000). The first of these papers discusses the long-run structural cointegrating VAR approach to modelling as it is applied to macroeconometric modelling. The paper makes explicit comparisons between this approach and the alternative approaches to macroeconometric modelling currently observed in the UK and elsewhere and describes the relative merits of the alternative approaches.

The core quarterly long-run structural VAR model of the UK economy is described in detail in Garratt *et al*. (1999a). The paper *first* describes a framework for long-run macroeconomic

[4] This work is described in Cunningham et al. (1998), Salazar, Smith Weale and Wright (1996, 1997), Salazar, Smith and Weale (1996) and Smith, Weale and Satchell (1998).

modelling, based on a rigorous derivation of the long-run steady state relationships expected to prevail between the main variables in a model of an open economy as expressed by economic theory. The emphasis is on arbitrage conditions, stock-flow equilibria and long run solvency conditions. This work represents an important extension to the previous empirical work on structural VAR models, providing a relatively sophisticated structure, relative to that of King *et al* (1991) or Mellander *et al*. (1992), for example, appropriate for the analysis of many open economy macroeconomic problems. *Second*, the paper describes a strategy that provides a practical approach to incorporating the long-run structural relationships suggested by economic theory in an otherwise unrestricted VAR model. And *third*, the paper applies the econometric techniques described in Section 2.1.1 above to estimate a model of the UK economy and to test the long-run properties predicted by the theory. The model is estimated over the period 1965q1-1995q4 and has the following variables: domestic and foreign outputs, domestic and foreign prices (both measured relative to oil prices), the nominal effective exchange rate, nominal domestic and foreign interest rates and real money balances.

Garratt *et al*. (1998) provides a complete account of the estimation of the core model of the UK and the tests conducted on the model. However, the construction of the model relied on considerable detailed preliminary work to understand the statistical properties of the macroeconomic time series and the nature of the relationships that exist between the variables of the model. An account of the experiences of the UK macroeconomy, an overview of the properties of the data, and a more detailed discussion of the process of model construction, based on data covering the period 1965q1-1998q4, is included in Garratt *et al*. (2000). This is a monograph which is intended to provide a more comprehensive description of the activity involved in building the core model and to act more generally as a primer for the application of the long-run structural VAR modelling approach. (See Question 4 of the Report on Dissemination for more details).

The economic theory elaborated in Garratt *et al*. (1998), and the statistical considerations for the empirical application, suggest that there are five long-run cointegrating relationships among the eight core variables of the macro-model. These relationships include the Interest Rate Parity relationship, a modified Purchasing Power Parity relationship, a relationship between domestic and foreign outputs, a trade balance relationship and a real money balance relationship. And as it turned out, over the period 1965q1-1995q4, we were not able to reject the null of the hypothesis that the number of cointegrating vectors is indeed five using a range of small sample adjusted critical values which allow for the presence of exogenous I(1) variables. Further, under the assumption that there are five long-run relationships, we obtained a model in which the freely-estimated parameters take sensible signs and are of plausible orders of magnitude when judged against the theory-based model elaborated in the paper.

In addition, following the methods developed in Pesaran and Shin (1999b) and PSS, we tested the validity of fourteen (over-identifying) restrictions, eleven of which were intrinsic to the theory, and three of which were consistent with the theory and were included for reasons of parsimony. Using small sample adjusted likelihood ratio tests, we were not able to reject these over-identifying restrictions, and from this we conclude that the estimated model is both theory and data consistent.

In order to evaluate the equations of the core model, we compared them with a set of benchmark ARMA models estimated separately on the first differences of the seven endogenous variables in the model. These benchmarks are constructed without reference to economic theory and provide representations of the variables based purely on their time series properties. Comparison with the estimated core model allows us to consider how much, if at all, the explanatory power and potential forecasting ability of the model is improved by the adoption of the long-run structural

modelling approach. It turns out that inclusion of the error correction terms in the model provide a superior fit, more sophisticated dynamics and improved diagnostics relative to the model which omits the effects of the presence of long run relationships.

To assess the contribution of the long-run relationships to the models dynamic properties, we also calculated Persistence Profiles (PP). The PPs provide information on the speed with which the different relations in the model, once shocked, will return to their long-run equilibria. For example, in the case of the modified Purchasing Power Parity relationship, the profile shows a steady decline towards its equilibrium value, with a half-life of 3.4 quarters. Approximately 80 per cent of the adjustment takes place within 9 quarters, and the full adjustment takes about five years to complete.[5] In contrast, the PP profile of the interest rate parity relationship, for example, shows a more rapid rate of adjustment towards its long-run value, with approximately 80 per cent of the adjustment having been completed within 6 quarters and full adjustment occurring within three to four years. These profiles, which are nor reliant on any identifying restrictions based on short-run dynamics, not only demonstrate the importance of the long-run relationships in influencing the dynamics of the macroeconomy, but also contain useful information on the relative strengths of the various equilibrating pressures exerted on different macroeconomic variables.

As an integral part of the work described in Garratt *et al* (1998, 1999a,b and 2000), we have devoted considerable time to the construction of a detailed and comprehensive database containing the quarterly data required to estimate the UK long run structural model. Garratt *et al*. (2000) provides a guide to the organisation, storage, and sources of the data. The need for a comprehensive, transparent and clearly documented database in the construction of a macromodel cannot be underestimated, in our opinion, and it is our intention that it is relatively straightforward to backtrack from any estimated model to the original data sources easily and rapidly. This is essential if the model is to be updated in the light of more recent data and if results are to be replicated.

### *2.3 The use of the model*

In Garratt *et al*. (1998, 1999a, 2000) we have developed a macro-econometric model of the UK economy with coherent and transparent long-run properties. The ability to test the validity of the long-run restrictions suggested by economic theory in the context of a small, but complete, macromodel is one of the strengths of the long-run structural VAR modelling approach, and the evidence obtained for our model suggests that the model is both data- and theory-consistent. The flexibility of the VAR modelling framework means that it is able to capture the complicated dynamic features of the data. The associated Persistence Profiles and Generalised Impulse Responses convey this complexity in a clear way and provide useful insights into the mechanisms by which the effects of the shocks are propagated across different macroeconomic variables and overtime. In addition to these general insights, however, the work of the project has considered a number of topics which draw on the modelling activity above and which have the potential for use in making decisions on the timing and conduct of macroeconomic policy and other decisions relating to macroeconomic events.

#### 2.3.1 Identifying the source of shocks and impulse response

One of the benefits derived from the development of the core macroeconomic model described in Section 2.2 above is the insight it provides on the difficulties involved in identifying 'structural' shocks, with a specific economic interpretation, or the impulse responses of variables to such

[5] It is worth noting that the speed of convergence of the modified Purchasing Power Parity towards its equilibrium observed here is much faster than the ones reported in the literature for the (unmodified) Purchasing Power Parity.

structural innovations. The presence of cointegrating relations between variables provides no information on the impact effect of different types of shocks or on the contemporaneous correlation structure of different structural innovations. Rather, the restrictions necessary for identification of structural effects require a tight description of the decision-rules followed by agents, incorporating information on agents' use of information and the timing and flows of information.

Starting with Sims (1980), a number of alternative (short-run) identification schemes have been advanced in the literature, without a clear consensus having been formed.[6] Such identification schemes are required, however, if the model is to be used in the analysis of the effects of shocks of particular types; e.g. shocks to monetary policy. In Garratt *et al*. (2000), we have considered a number of the sets of restrictions suggested by these identification schemes, finding little evidence so far in support of any one of them. If this remains the case, then there is a strong case for the use of GIR's and PP's in the analysis of the model dynamics, since these do not rely on identification schemes involving the short-run dynamics, and it would suggest that the impulse response results obtained and described in the literature (on the basis of identification schemes of this sort) should be treated with some caution.

### 2.3.2 Probability forecasting

An important area in which the estimated model of the UK economy has been applied is in probability forecasting, reported in Garratt *et al*. (1999b). With a few notable exceptions (e.g. the Bank of England and the National Institute) macroeconomic forecasts are generally presented in the form of point or central forecasts and their uncertainty is characterised (if at all) by forecast intervals. As discussed in Granger and Pesaran (1999a, 1999b), for most decision problems, reliance on point forecasts will not be sufficient and forecasts of the probability that an event will occur will be far more helpful. The use of 'probability forecasts' can be particularly helpful in the presentation and discussion of macroeconomic policy: it is important that policy statements are made in probabilistic terms if the public's perception of the credibility of the policy has important implications for its success or failure.

In Garratt *et al*. (1999b), we discuss the use of event probability forecasts for the characterization of the various sources of uncertainty that surround forecasts from a macroeconomic model. The event of interest can be defined with respect to the values of a single variable or a set of variables, measured at a particular point in time, over a sequence of time periods, or over different time intervals in the future. We consider alternative ways of characterizing the uncertainty surrounding forecasts from a macroeconomic model and argue that probability forecasts convey information on this uncertainty in a straightforward way and one which is superior to many alternatives, including the use of prediction intervals.

Having described formally a framework for the analysis of probability forecasts in a general model, we provide probability estimates of a number of macroeconomic events using our cointegrating macroeconometric model of the UK. Using estimates for the model computed over the extended period 1965q1-1998q4 and initially abstracting from parameter uncertainty, we focus on 'future uncertainty' due purely to the stochastic nature of the model under consideration. The events chosen focus on the likelihood of the economy going into recession over various time frames and the likelihood of the inflation rate hitting the target which currently is considered explicitly by the Bank of England in implementing monetary policy. We consider these variables both individually and together. We then extend the discussion to allow for 'parameter uncertainty'. In this case, we compute point estimates of probability forecasts and of their confidence intervals.

Our plan is to make available, without charge, probability forecasts through collaboration with Cambridge Econometrics plc, a private-sector company specialising in modelling work and

[6] See, for example, Bernanke (1986), Christiano and Eicenbaum (1992), Cochrane (1998), Crowder et al. (1999), or Wickens (1999).

forecasts. Our hope is that the use of our macroeconomic model in obtaining forecasts will both encourage the use of probability forecasts, as a means of conveying forecast uncertainty in a more transparent and honest way, and will be helpful in decision-making where this is influenced by future macroeconomic circumstances.

### 2.3.3 Comparison of Monthly and Quarterly Models

Both methods designed to take into account interpolation errors described in Section 2.2 are suitable for the estimation of equations with I(0) variables, or in first differences of I(1) variables, but they do not offer the means for estimating co-integrating relationships. However, a monthly version of our quarterly macroeconomic model of the UK can be readily constructed if we use the same co-integrating relationships as are obtained in the quarterly model. This is eminently reasonable, in our view: there is unlikely to be anything to be gained by trying to estimate co-integrating relationships from monthly data since co-integration is essentially a long-run phenomenon. The residuals of the co-integrating relationships are I(0) variables which can be used in either the maximum likelihood or GLS estimation method. The covariance matrix of the interpolation errors associated with the different variables and the co-integrating residuals is easily calculated. Although of large dimensions it does not require frequent manipulation, so that the GLS approach is quite manageable. The outcome is that we can obtain a monthly version of the quarterly model which, by construction, has the same long-run structural relationships. Of course, there remains the question of whether the monthly model is in any sense superior to the quarterly version.

We make three comparisons between the monthly and quarterly models. Specifically, for each fitted quarterly data point, we can consider three different monthly estimates: the first is calculated on the assumption that no data exist for months in the current quarter; the second assumes that one month is known; and the third that two months' data are known. All of these are competing against the fitted quarterly values calculated from the previous data of each quarter. In order to calculate them, we have to evaluate within-sample ‘forecasts' one, two and three months ahead.

We compare the three fitted monthly values with the quarterly fitted values in two ways. *First*, we present the R-squared values comparing each of the four fitted values with the true data. The results, given in Weale (1999), show that fitted values calculated from the monthly model using no information for the current quarter are all less correlated with the true quarterly data than the fitted values from the quarterly model. With one month's data, the R-squared values are more equal: for example, the exchange rate is now forecast much better with the monthly model while the money/gdp ratio is still forecast much worse. With two months' data, all the quarterly variables except the foreign interest rate are fitted better by using the monthly model to estimate the third month of the quarter than by using the quarterly model. The results using the model corrected for
measurement error are scarcely different from those given by the OLS model.

The second means of comparing the two models involves estimating a series of regression equations, explaining the true data by the quarterly and each of the three monthly fitted values separately. The coefficients show the 'optimal' weights for combining the two models in order to explain the quarterly data. They fit the pattern which might be expected given the results for the R-squared values. When combining a fitted value from the quarterly model with one in which all three months of the same quarter are fitted using the monthly model, very little weight is given to the monthly model. When only two months need to be forecast, greater importance is given to the monthly model, but the balance of importance lies with the quarterly model. It is only when two months' data are known and one month is forecast that the importance of the estimates from the monthly model increases towards or above those from the quarterly model.

The results in Weale (1999) point in the same direction. The quarterly model performs better than the monthly model for forecasting any of the model variables in a new quarter. However, the monthly model is a useful tool for forecasting the remaining months of the current quarter, once one or two months' data are already known. Given the importance of current data in any forecasting exercise, this suggests that quarterly forecasts can be improved by using monthly models to build up a picture of the current quarter. A similar conclusion was reached by Salazar and Weale (1999) using a much smaller model estimated by maximum likelihood and in a separate context by Kapetanios (1999).

2.3.4 Other applications undertaken during the project

The research undertaken to develop the necessary econometric methods and to construct the quarterly and monthly versions of the UK model has generated a host of related papers investigating macroeconomic relationships using the same methods during the project. As well as being pieces of work in their own right, these papers have served two functions. The first purpose served is as a test bed for the proposed econometric methodology, and findings in the empirical applications have often influenced the direction of the development of the econometric methods. And the second is purpose is to investigate alternative models of the macroeconomy or to consider ways in which the core model might be extended to provide a more complete model of the UK economy. In the labour market, Henry and Lee (1998,1999) focus on issues of identification of wage and employment equations. In the area of international macro, Pesaran and Shin (1996), Astley and Garratt (1998) and Pesaran, Shin and Smith (1999b) all consider the dynamic responses of domestic (UK) and foreign prices, exchange rates and interest rates to shocks in the context of a VAR allowing for unit roots and cointegration. And Lee (1998), Garratt and Pierse (1996) and Lee and Shields (1998, 1999a,b) each address business cycle issues using a VAR approach.

## *3. Concluding remarks*

We believe that the project has achieved its main objectives. *First*, it has contributed to the development of a new econometric methodology. The work on long-run structural modelling describes an approach for time-series modelling in cointegrating VAR models (and develops the techniques necessary to implement this approach) which we hope will be widely adopted in applied econometric research. *Second*, we have successfully utilised this methodology, along with a new strategy which provides a practical approach to incorporating the long-run structural relationships suggested by economic theory in an otherwise unrestricted VAR model, to produce a small but reasonably comprehensive macroeconometric model of the UK economy. The description of the modelling work provides one of the first examples of the use of the econometric techniques that have been developed on the project in an applied context while the model itself provides a valuable vehicle with which to analyse long run behavioural macroeconomic relationships and

the short run dynamics. *Third*, the project has analysed the use of monthly data in macroeconometric modelling by developing the techniques necessary to produce appropriate monthly data and by providing a monthly version of the macroeconometric model of the UK economy for comparison with the quarterly version. And *fourth*, the modelling work of the project has been applied to the analysis of a range of macroeconomic issues of interest to academics, business community and policy makers.

While we have applied the model to the analysis of a variety of macroeconomic issues, there remain a number of important and interesting areas that could be further explored. In particular, the project has opened new avenues of research in long-run modeling, dynamic response analysis and probability forecasting. Such research should be of particular interest in the development of techniques for the real time analysis of economic problems. The analysis undertaken under this research program should be viewed as initial steps in this direction and is an area that the members of the research group hope to pursue in the future.

## 4. References

(Papers directly related to the project either directly or indirectly are listed separately on pages 29-32)


Artis, M., Bladen-Hovell, R., and W. Zhang (1995), 'Turning Points in the International Business Cycle: An Analysis of the OECD Leading Indicators for the G7 Countries', *OECD Economic Studies*, 24, 125-165.

Blake, A.P. (1996), 'Forecast Error Bounds By Stochastic Simulation', *National Institute Economic Review*, May, 72-79.

Blanchard, O.J. and D. Quah (1989), 'The Dynamic Effects of Aggregate Demand and Supply Disturbances', *American Economic Review*, 79, 655-673.

Champernowne, D.G. (1960), 'An Experimental Investigation of the Robustness of Certain Procedures for Estimating Means and Regressions Coefficients', *Journal of the Royal Statistical Society*, Series A, 123, 398-412.

Christiano, L.J. and M. Eichenbaum (1992), 'Liquidity Effects and the Monetary Transmission Mechanism', *American Economic Review*, 82, 346-353.

Christiano, L.J., M. Eichenbaum and C.L. Evans (1998), 'Modeling Money?', *NBER Working Paper* No. 3916, 98/1.

Cooley, T. (ed.) (1995), *Frontiers of Business Cycle Research*. Princeton: Princeton University Press.

Cooley, T. and S. LeRoy (1985), 'Atheoretical Macroeconometrics: A Critique', *Journal of Monetary Economics*, 16, 283-308.

Dickey, D.A. and W. A. Fuller (1979), 'Distribution of the Estimators for Autoregressive Time Series With a Unit Root', *Journal of the American Statistical Association*, 74, 427-431.

Doan, T., R. Litterman and C. Sims (1984), 'Forecasting and Conditional Projections Using Realistic Priori Distributions', *Econometric Reviews*, 3, 1-100.

Engle, R. and C.W.J. Granger (1987), 'Cointegration and Error-Correction: Representation, Estimation and Testing', *Econometrica*, 55, 251-76.

Fair, R.C. (1993), 'Estimating Event Probabilities From Macroeconometric Models Using Stochastic Simulation', in J.H Stock and M.W. Watson (eds.) Business Cycles, Indicators, and Forecasting *NBER Studies in Business Cycles* Volume 28. Chicago: University of Chicago Press.

Fair, R.C. (1994), *Testing Macroeconometric Models.* London: Harvard University Press.

Fuller, W.A. (1987), *Measurement Error Models*. Chichester: John Wiley

Granger, C. and P. Newbold (1974), 'Spurious Regressions in Econometrics', *Journal of Econometrics*, 2, 111-120.

Harvey , A.C. (1989), *Forecasting, Structural Time Series Models and The Kalman Filter*. Cambridge University Press.

Johansen, S. (1991), 'Estimation and Hypothesis Testing of Cointegrating Vectors in Gaussian Vector Autoregressive Models', *Econometrica*, 59, 1551-80.

Johansen, S. (1995), *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. Oxford: Oxford University Press.

Kapetanios, G. (1999). Chapter 17 of *Monthly Interpolation and Leading Indicators*. Report submitted to Eurostat by A.P. Blake, G. Camba-Mendez, G. Kapetanios, and M.R. Weale. Forthcoming.

Kim, K. and A.R. Pagan (1995), 'The Econometric Analysis of Calibrated Macroeconomic Models', Chapter 7 M.H. Pesaran and M. Wickens (eds.) *Handbook of Applied Econometrics: Macroeconomics*. Oxford: Basil Blackwell.

King R.G., C.I. Plosser, J.H. Stock, and M.W. Watson (1991), 'Stochastic Trends and Economic Fluctuations', *American Economic Review*, 81, 819-840.

Kydland, F. and E. Prescott (1982), 'Time to Build and Aggregate Fluctuations', *Econometrica*, 50, 1345-70.

Levtchenkova S., A.R. Pagan, and J.C. Robertson (1998), 'Shocking Stories', *Journal of Economic Surveys*, 12, 507-532.

Litterman, R. (1986), 'Forecasting with Bayesian Vector Autoregressions - Five Years of Experience', *Journal of Business and Economics Statistics*, 4, 25-38.

Long, J.B. and C. Plosser (1983), 'Real Business Cycles', *Journal of Political Economy*, 91, 39-69.

Lucas, R.E. (1976), 'Econometric Policy Evaluation: A Critique', in K. Brunner and A.H. Meltzer (eds) The Phillips Curve and Labour Markets, *Carnegie Rochester Series on Public Policy*, Volume 1, 19-46.

Mellander, E., A. Vredin, and A. Warne (1992), 'Stochastic Trends and Economic Fluctuations in a Small Open Economy', *Journal of Applied Econometrics*, 7, 369-394.

Nelson, C.R. and C.I. Plosser (1982), 'Trends and Random Walks in Macro-Economic Time Series', *Journal of Monetary Economics*, 10, 139-162.

Obstfeld, M. and K. Rogoff (1996), *Foundations of International Macroeconomics*. Cambridge: Massachusetts Institute of Technology Press.

Pesaran, M.H. and R.P. Smith (1995), 'The Role of Theory in Econometrics', *Journal of Econometrics*, 67, 61-79.

Phillips, P.C.B. (1991), 'Optimal Inference in Cointegrated Systems', *Econometrica*, 59, 283-306.

Sims, C. (1980), 'Macroeconomics and Reality', *Econometrica*, 48, 1-48.

Smith, R.P. (1994), 'The Macromodelling Industry: Structure, Conduct and Performance', in S.G. Hall (ed.) *Applied Economic Forecasting Techniques*. London: Harvester Wheatsheaf.

Yule, G.U. (1926), 'Why Do we Sometimes Get Nonsense Correlations Between Time-Series?' *Journal of the Royal Statistical Society*, 60, 812-54.

**Question 4: Dissemination**

In what follows, we provide details of the dissemination of the work undertaken by this project. This has taken the form of published, forthcoming and working papers and presentations at various conferences, seminars and invited lectures. Below, we list the project output under four headings; papers directly related to the project; papers written by project members but related to the project only indirectly; the monograph which brings together all the work of the project into one publication; and conferences, seminars and lectures.

***I. Papers Directly Related to the Project***


Astley, M., and A.Garratt (1998), 'Exchange Rates and Prices: sources of sterling real exchange rate fluctuations 1973-94', *Bank of England Discussion Paper*, No. 85.

Cunningham, A., R.J. Smith and M.R. Weale, (1998), 'Measurement Errors and Data Estimation: the Quantification of Survey Data', in I.G. Begg and S.G.B. Henry (eds.) *Applied Economics and Public Policy*, CUP.

Garratt, A., K. Lee, M.H. Pesaran, and Y. Shin (1998), 'A Long Run Structural Macroeconometric Model of the UK', *DAE Working Paper No. 9812*, University of Cambridge. Revised version (October 1999) ( www.econ.cam.ac.uk/faculty/pesaran/ukm95.pdf)

Garratt, A., K. Lee, M.H. Pesaran and Y. Shin (1999a), 'A Structural Cointegrating VAR Approach to Macroeconometric Modelling', in S. Holly and M. Weale (eds.*) Econometric Modelling; Techniques and Applications*, Cambridge University Press (forthcoming). Available as *DAE Working Paper 9823* (www.econ.cam.ac.uk/faculty/pesaran/ni99.pdf.)

Garratt, A., Lee, K., Pesaran, M.H. and Y. Shin (1999b), 'Forecast Uncertainties in Macroeconometric Modelling', *unpublished manuscript*, University of Cambridge (forthcoming. http://www.econ.cam.ac.uk/dae/svar/).

Garratt, A., K. Lee, M.H. Pesaran, and Y. Shin (2000*), A Structural Cointegrating Macroeconomic Model of the UK*, monograph under preparation.

Garratt, A., and R.G. Pierse, (1996), 'Common stochastic trends, cycles and sectoral fluctuations: a study of output in the UK', *unpublished manuscript*, University of Cambridge

Granger, C.W.J. and M.H. Pesaran (1999a), 'A Decision Theoretic Approach to Forecast Evaluation', *DAE Working Paper No. 9618*, University of Cambridge. Revised version forthcoming in W.S. Chan, W.K. Li and H. Tong (eds) *Statistics and Finance: An Interface*, World Scientific Publishing Co.

Granger, C.W.J. and M.H. Pesaran (1999b), 'Economic and Statistical Meaures of Forecast Accuracy', *DAE Working Paper No.9910*, University of Cambridge. (www.econ.cam.ac.uk/faculty/pesaran/gp1999.pdf.)

Henry, S.G.B. and K. Lee, (1998), 'Unemployment, Wage Dispersion and Labour Market Flexibility', in J. Grieve-Smith and J. Michie (eds.) *Full Employment without Inflation*, Academic Press, London.

Henry, S.G.B. and K. Lee, (1999), 'Identification and Estimation of Aggregate Wage and Employment Equations: An Application of the Long-Run Structural VAR Modelling Approach', *unpublished manuscript*, University of Leicester.

Lee, K., (1998), 'Cross-Country Interdependence in Growth Dynamics: A Model of Output Growth in the G7 Economies, 1960-1994', *Weltwirtschaftliches Archiv*, 134, 3, 367-403.

Lee, K. and K. Shields, (1998), 'Expectations Formation and Business Cycle Fluctuations: An Empirical Analysis of Actual and Expected Output in UK Manufacturing, 1975-96', *unpublished manuscript*, Department of Economics, University of Leicester (www.le.ac.uk/economics/kcl2/).

Lee, K. and K. Shields, (1999a), 'Measuring Trend Output Using Actual and Expected Output in UK Manufacturing, 1975-96', *unpublished manuscript*, Department of Economics, University of Leicester. (www.le.ac.uk/economics/kcl2/).

Lee, K. and K. Shields, (1999b), 'Information, Business Surveys and Measurment of Output Trends in Six European Economies', *unpublished manuscript*, Department of Economics, University of Leicester. (www.le.ac.uk/economics/kcl2/).

Pesaran, M.H. (1997), 'The Role of Economic Theory in Modelling the Long Run', *Economic Journal*, 107, 178-91.

Pesaran, M.H. and Y. Shin (1996), 'Cointegration and Speed of Convergence to Equilibrium', *Journal of Econometrics*, 71, 117-43.

Pesaran, M.H. and Y. Shin (1998), 'Generalized Impulse Response Analysis in Linear Multivariate Models', *Economics Letters*, 58, 17-29.

Pesaran, M.H. and Y. Shin, (1999a), 'An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis', in S. Strom (ed) *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium.* Cambridge: Cambridge University Press.

Pesaran, M.H. and Y. Shin (1999b), 'Long-Run Structural Modelling', *DAE Working Paper* No. 9419, University of Cambridge. Revised version (April 1999) (www.econ.cam.ac.uk/faculty/pesaran/lrs.pdf.)

Pesaran, M.H., Y. Shin, and R.J. Smith (1999a), 'Structural Analysis of Vector Error Correction Models with Exogenous I(1) Variables' , *Journal of Econometrics*, forthcoming.

Pesaran, M.H., Y. Shin and R. J. Smith, (1999b), 'Bounds Testing Approaches to the Analysis of Long Run Relationships', *DAE Working Paper* No 9907, University of Cambridge. (www.econ.cam.ac.uk/faculty/pesaran/pss1.pdf.) Under revision.

Pesaran, M.H. and R.P. Smith (1997), 'New Directions in Applied Dynamic Macroeconomic Modelling', in R. Dahel and I. Sirageldin (eds) *Models for Economic Policy Evaluation Theory and Practice: An International Experience*, Greenwich: JAE Press Inc.

Pesaran, M.H. and R.P. Smith (1998), 'Structural Analysis of Cointegrating VARs', *Journal of Economic Surveys*, 12, 471-505. Also in L. Oxley and M. McAleer (eds) *Practical Issues in Cointegration Analysis*, Oxford:Basil Blackwell.

Salazar, E.L. and M. Weale, (1999), 'Monthly Data and Short-term Forecasting: an Assessment of Monthly Data in a VAR Model'. *Journal of Forecasting*, forthcoming.

Salazar, E.L, R.J. Smith, M.R. Weale and S.H. Wright. (1996), 'An Indicator of Monthly GDP', *unpublished manuscript*, National Institute of Economic and Social Research.

Salazar, E.L., R.J. Smith and M.R. Weale. (1996). 'Interpolation using a Dynamic Regression Model: Specification and Monte-Carlo Properties', *unpublished manuscript*, National Institute of Economic and Social Research.

Salazar, E.L., R.J. Smith, M.R. Weale and S.H. Wright. (1997). 'A Monthly Indicator of GDP'. *National Institute Economic Review*. 161, 84-90. A non-technical account of the unpublished paper including up-to-date estimates.

Smith, R.J., M.R. Weale and S. Satchell. (1998). 'Measurement Error with Accounting Constraints: Point and Interval Estimation for Latent Data with an Application to UK Gross Domestic Product.' *Review of Economic Studies*, 65(1), No. 222, 109-134.

Weale, M. R. (1996), 'An Assessment of OECD and UK Leading Indicators'. *National Institute Economic Review*. No. 156,. 63-71.

Weale, M. R. (1999), 'A Monthly Structural VAR of the UK Economy', *unpublished manuscript*, National Institute for Economic Research.

### *II. Papers Indirectly Related to the Project*

Astley, M. and A. Garratt (1996), 'Interpreting Sterling Exchange Rate Movements', *Bank of England Quarterly Bulletin*, 36, 394-404.

Binder, M. and M.H. Pesaran (1995), 'Multivariate Rational Expectations Models and Macroeconometric Modelling: A Review and Some New Results', Chapter 3 in M.H. Pesaran and M. Wickens (eds) *Handbook of Applied Econometrics: Macroeconomics*. Oxford: Basil Blackwell.

Binder M. and M.H. Pesaran (1996), 'Stochastic Growth Models and Their Econometric Implications', *Journal of Economic Growth*, 4, 139-183.

Binder M., M.H. Pesaran and S.H. Samiei, (1999), 'Solution of Non-Linear Rational Expectations Models with Applications to Finite-Horizon Life-Cycle Models of Consumption', *Journal of Computational Economics*, forthcoming. (www.econ.cam.ac.uk/faculty/pesaran/nlre.pdf)

Coe, P.J., (1997), 'Financial Crises and Financial Reform During the Great Depression: A Regime Switching Approach', *unpublished manuscript*, University of Essex.

van Garderen, K-J., K.C. Lee and M.H. Pesaran, (1999), 'Cross-Sectional Aggregation of Nonlinear Models', *Journal of Econometrics*, forthcoming. (www.econ.cam.ac.uk/faculty/pesaran/aggnon.pdf)

Kapetanios, G., (1998a), 'Essays on the Econometric Analysis of Threshold Models', *PhD Thesis*, University of Cambridge.

Kapetanios, G., (1998b), 'Threshold Models for Trended Time Series', *DAE Working Paper* No. 9905, University of Cambridge.

Kapetanios, G., (1998c), 'Model Selection in Threshold Models', *DAE Working Paper* No. 9906, University of Cambridge.

Koop G., M.H. Pesaran and S.M. Potter, (1996), 'Impulse Response Analysis in Nonlinear Multivariate Models', *Journal of Econometrics*, 74, 119-147.

Lee, K., M.H. Pesaran, and R.P. Smith (1997), 'Growth and Convergence in a Multi-Country Empirical Stochastic Solow Model', *Journal of Applied Econometrics*, 12, 357-392.

Lee, K., M.H. Pesaran and R.P. Smith (1998), 'Growth Empirics: A Panel Approach - A Comment', *Quarterly Journal of Economics*, 113, 319-323.

McCabe, B.P.M., S.J. Leybourne, Y Shin, (1997), 'A Parametric Approach to Testing the Null of Cointegration', *Journal of Time Series*, forthcoming.

Pesaran, B. and M.H. Pesaran, (1995), 'A Non-Nested Test of Level-Differenced versus Log-Differenced Stationary Models', *Econometric Reviews*, 14, 213-228.

Pesaran, M.H., and S.M. Potter, (1997), 'A Floor and Ceiling Model of US Output', *Journal of Economic Dynamics and Control*, 21, 661-695.

Pesaran, M.H., and F.J. Ruge-Murcia, (1996), 'Limited-Dependent Rational Expectations Models with Stochastic Thresholds', *Economics Letters*, 51, 267-276.

Pesaran, M.H., and F.J. Ruge-Murcia, (1999a), Analysis of Exchange Rate Target Zones using a Limited-Dependent Rational Expectations Model with Jumps, *Journal of Business and Economic Statistics* 17, 50-66.

Pesaran, M.H. and F.J. Ruge-Murcia (1999b), 'Inflation Targets with Asymmetric Preferences', *unpublished manuscript*, University of Cambridge.

Pesaran, M.H., and H. Samiei, (1995), 'Limited-Dependent Rational Expectations Models with Future Expectations', *Journal of Economic Dynamics and Control*, 19, 1325-1353.

Pesaran, M.H., and A. Timmermann, (1995), 'Predictability of Stock Returns: Robustness and Economic Significance', *Journal of Finance*, 1995, 50, 1201-1228.

Pesaran, M.H., and A.Timmermann, (2000), 'Recursive Modelling Approach to Predicting UK Stock Returns', *Economic Journal*, forthcoming.

### *III. The Monograph*

We have made considerable progress on the preparation of a monograph entitled *A Structural Cointegrating Macroeconomic Model of the UK*. The aim of the monograph Garratt *et al*. (2000) is to bring together the theoretical, econometric and empirical aspects of the project into a single publication. As space constraints are not as tight in this format as they are in academic journal articles, we are able to discuss a number of results and computational aspects that have not been published elsewhere.

The structure of the monograph will begin with a detailed description of the structural VAR approach to macroeconometric modelling and it's relation to alternative modelling approaches. We provide a full account of the long-run theory used to model an open economy such as the UK. The econometric methods are then described along with a detailed account of the estimation procedure used to construct the core model. This involves an intermediate stage where we consider sub-systems involving modules. Modules contain only variables relating to one of the long run relationships suggested by economic theory. Having examined the modules we then proceed onto estimating the full model which estimates all five long run relationships. This lends transparency to our estimation procedure for pedagogic purposes, allows us to examine each of the long run relationships without dealing with the large number of parameters and helps further our understanding of the model's ability to match the data. Finally, we outline the uses of the model, emphasising the importance of the model in the production of probability forecasting.

The monograph aims to bring together the work of the project as it relates to the construction of our core model in a single coherent entity. Our intention is that we can elaborate on some of the arguments contained in the associated academic journal articles. Our hope is that the monograph will act as a primer for those wishing to use the long-run structural VAR approach to modelling in other applied work.

In the spirit of transparency and with a pedagogic role in mind, the monograph will contain an accompanying disk or set of disks, with the full databank and all the relevant files, which when used with Microfit, WinSolve and GAUSS programmes will enable the reader to reproduce the estimation results, impulse responses and probability forecasts reported.

## *IV. Conferences, Seminars, Invited Lectures and other Associations*

M. Hashem Pesaran

*Invited Lectures:*
National Bureau for Economic Research conference on Forecasting, Boston, USA, July 1995
Political, Institutional and Economic Transitions. ESRC Development Economics Study Group Annual Conference held at University of Leicester, March 1996.
Sixth Biennial International Conference on Panel Data, Amsterdam, 1996.
National Bureau for Economic Research Summer Institute workshop on Empirical Methods in Macro and Forecasting, Boston, USA, July 1997
Keynote Address to Symposium on Computation in Economics, Finance and Engineering: Economic Systems, held in Cambridge England, June 1998 (organized by the Society for Computational Economics)
National Bureau for Economic Research and National Science Foundation joint meeting on Empirical Methods in Macroeconomics, Boston, USA, July 1998
British Association Annual Festival of Science, Cardiff, September 1998
Autumn Conference of Inquire Europe (Institute for Quantitative Investment Research), Istanbul, October 1998
Country Risk Conference, Paris, January 1999 (organized by Groupe Coface)

*Seminars:*
1994/95:
Research Department, International Monetary Fund; London School of Economics; London Business School; Economic Research Forum Conference, Rabat, Morocco; School of Oriental and African Studies, University of London; University of Kent, UK; Norwegian Academy of Science and Letters, Oslo, Norway; Bank of England, London, UK; Iranian Cultural Society, Washington, USA; CEPR Conference, Universite Libre de Bruxelles, Belgium; London Guildhall University, UK

1995/96:
University of California at Los Angeles, USA; University of California at San Diego, USA; University of California at Riverside, USA; Ohio State University, USA; University of Maryland, USA; University of Minnesota, USA; University of Pennsylvania, USA

1996/97:
Bank of England, London, UK; Royal Statistical Society, London, UK; Econometric Institute, Erasmus University Rotterdam, The Netherlands; University of Cambridge, UK; Meteorological Office, Bracknell, UK; Foreign & Commonwealth Office, London, UK; Cambridge University Iran Society, Cambridge, UK; University of Manchester Institute of Science & Technology, UK; Judge Institute of Management Studies, University of Cambridge, UK; University of Edinburgh, UK; Center for Economic Studies, University of Munich, Germany; University of Manchester, UK; Nuffield College, Oxford, UK; University of Warwick, UK; Central Bank of Iran, Tehran, Iran;

1997/98:
University of Southern California, USA; University of California at Los Angeles, USA; University of California at San Diego, USA; University of Iowa, USA; University of California at Riverside, USA; University of Wisconsin at Madison, USA; Guelph University, Canada; University of Toronto, Canada; London School of Economics, London, UK; University of Wisconsin at Milwaukee; University of Bielefeld, Germany

1998/99:
University of Birmingham, UK; Koc University, Istanbul, Turkey; Royal Meteorological Society Conference, London, UK; University of Illinois at Urbana-Champaign, USA; HM Treasury, London, UK; London Business School, UK; Tor Vergata University, Rome, Italy; University of Southampton, UK; European University Institute, Florence, Italy.; Central Bank of Iran, Tehran, Iran.; London School of Economics, UK; International Workshop on Financial Statistics, Hong Kong.

Kevin Lee

*Conferences:*
Conference on 'Full Employment without Inflation', Robinson College, Cambridge, May 1996.
Professorial Inaugural Lecture, University of Leicester, February 1997
British Council Conference on 'Financial Liberalisation: Impact on the European Community and India', Bombay, India, February 1997.
Annual Conference of the Macroeconomic Modelling Bureau, University of Warwick, July 1997.
ESRC and NIESR Conference on 'Macroeconomic Modelling and Economic Policy', London Chamber of Commerce, January 1998.
Royal Economic Society Annual Conference, Univ. of Warwick, April 1998.
EEEG Labour Economics Study Group Annual Conference, University of Newcastle, June 1998.
Annual Conference of the Macroeconomic Modelling Bureau, University of Warwick, July 1998.

*Seminars:*
University College London, May 1997; Queen Mary and Westfield College, November 1997; Univ. of Sheffield, April 1998; Cardiff Business School, March 1998; University of Southampton, February 1999; University of Surrey, February 1999; University of Manchester, February 1999

Anthony Garratt

*Conferences:*
Annual Conference of the Macroeconomic Modelling Bureau, University of Warwick, July 1997.
Royal Economic Society Conference, University of Warwick, April 1998.

*Seminars:*
University of Exeter, May 1998; Bank of England, Centre for Central Banking Studies, September 1998; Bank of England staff seminar, September 1998; University of Glasgow, November 1998; University of Essex, December 1998; Birkbeck College, February 1999.

Yongcheol Shin

*Conferences:*
ESRC Macroeconomic Modelling Seminar, University of Warwick, July 1997 and July 1998.
7th International Convention of the Korean Economic Association at Pusan, August, 1996.
Royal Economic Society Annual Conference at University of Wales Swansea, April, 1996.
Econometric Society Winter Meeting at San Francisco, January, 1996.

*Seminars:*
University of Edinburgh, March 1999.

Martin Weale

*Conferences:*
ESRC Macromodelling Bureau Conference, Warwick, July 1997.

*Other Associations:*
Chairman of the National Accounts User Group and of the ONS Academic Panel.

Martin Weale has had very considerable interaction with users of monthly data. The National Institute began publishing estimates of monthly GDP in April 1998 having developed, as part of this project the methods it had originally worked on for the Central Statistical Office. These are increasingly reported in the press and are one of the pieces of data supplied to the Monetary Policy Committee. Martin Weale is also periodically an expert witness to the Treasury Select Committee (Weale, 1998) and is Chairman of the Office for National Statistics Academic Panel. His major
user interaction has been the Review of Average Earnings mentioned above. He has also presented his work on monthly data to Eurostat and this has resulted in a substantial contract from Eurostat to prepare estimates of monthly GDP for other European countries and to develop short-term
forecasting models. It is expected that the output of this work will be used by the European Central Bank in setting interest rates.

The work on monthly modelling has made possible the publication of monthly estimates of GDP by the National Institute. These are widely reported and are used by the Monetary Policy Committee as an input into the setting of interest rates. A number of users pay for delivery of the data 1.5 hours ahead of the press notice, which meets the costs of regular production by the National Institute.

**Question 9. Other Issues**

Staffing and Organisation

The research staff who were involved with the project were:

Anthony Garratt(Senior Research Officer, DAE Cambridge, Oct 1996 - May 1999 [20%])
Brian Henry (Principal Investigator, DAE Cambridge, June 1995 - April 1996 [20%])
Kevin Lee (Co-Applicant, Univ. of Leicester, June 1995 - May 1999 [15%])
Eduardo Salazar (Research Fellow, NIESR, Jan 1996 - Dec 1997 [100%])
Yongcheol Shin(Lecturer, University of Edinburgh, June 1995 - May 1997 [100%])
M. Hashem Pesaran(Co-Applicant, Univ. of Cambridge, June 1995 - May 1999 [unfunded])
Martin Weale (Co-Applicant, NIESR, Jan 1996 - May 1999 [unfunded])

After the research proposal was approved, three of the four original Applicants moved from Cambridge to take up appointments at other institutions: Brian Henry became Research Director at the Centre for Economic Forecasting at the London Business School; Kevin Lee took up a Chair at the University of Leicester; and Martin Weale became Director at the National Institute. The moves by Professor Lee and Mr. Weale did not change the plans for project, and their commitment to the project continued to be as set out in the research grant application. Professor Henry, on the other hand, was not able to fulfil his commitments to the project described in the original proposal, and left the project.

Anthony Garratt, previously of the Bank of England, was appointed to the project to replace Professor Henry. Dr. Garratt was appointed as a Senior Research Officer in the DAE from Oct. 1996 until the end of the project in May 1999. The ESRC had provided funds to cover 20% of Professor Henry's time over the four years of the project. The funds released by his withdrawal from the project provide partial funding for Dr. Garratt's appointment, although this money has to be supplemented by other sources of finance to cover its cost. The project members, and the Director of the DAE, were willing to underwrite this additional funding in order that the project could continue.

The main part of the money awarded by the ESRC provided for the equivalent of one researcher employed over the four-year period. We chose to spend this money on two researchers over the course of the first two years of the project: Yongcheol Shin was employed at the DAE in Cambridge and Eduardo Salazar was employed at the National Institute. The project continued over the remaining two years of the Programme through the continued partial funding of Anthony Garratt (20%) and Kevin Lee (15%) by ESRC and through the support of the DAE and the Isaac Newton Trust of Trinity College Cambridge, who provided funds for Anthony Garratt and Yongcheol Shin through the latter two years of the project.

The project was able to maintain its cohesion through the involvement of the core members of the research group comprising Pesaran, Lee, Garratt and Shin (at different times and in different capacities) on the ESRC-funded project on 'Econometric Analysis of Non-Linear Dynamic Models' (Ref: R000235524). This project was completed at the end of 1998 and was recently evaluated as 'Outstanding' by the ESRC. There were strong complementarities in the work of the two projects, as demonstrated in the list of papers provided under the heading '4. Dissemination' as being directly related to the project. Further, on the basis of the two projects, we were able to raise separate research money from the Newton Trust of Trinity College, Cambridge to finance the involvement in the project of a number of visitors and associates. This has provided an invaluable opportunity for project members to discuss their ideas with academics from abroad.

Project Associates/Visitors

*Associates:*
Professor Richard J. Smith (University of Bristol, UK)
Professor Ron Smith (Birkbeck College, University of London, UK)

*Visitors:*
Prof. C.W.J. Granger (University of San Diego, California): August to October 1998 (7 weeks).
Prof. M. Binder (University of Maryland): August 1996 (2 weeks); July 1997 (3 weeks).
Prof. Frank X. Diebold (University of Pennsylvania): July/August 1998 (4 Weeks).