A small structural empirical model of the UK monetary transmission mechanism

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Abstract

In this paper we estimate a structural empirical model of the UK monetary transmission mechanism, which can be used for policy analysis and forecasting. We model a small system of eight variables that theoretically have an important role in the transmission mechanism. The aim is to decompose the movements of each of these variables into a small number of independent underlying forcing processes or 'shocks', with a well-defined economic interpretation. To do this we estimate a statistical (VAR) model of the data, on which we impose a minimal number of identifying restrictions. Cointegration analysis is also used to distinguish between permanent shocks, which drive the stochastic trends of the system, and temporary shocks, which have purely cyclical effects.

We find that, in addition to identifying shocks to productivity, domestic demand, external demand and the foreign exchange risk premium, we are able to distinguish between several types of monetary shock. In particular, we are able to make a distinction between 'permanent' monetary policy shocks, attributable to changes in the underlying nominal target of the authorities, and 'temporary' policy shocks, reflecting either policy 'errors' or transitory deviations from the authorities' reaction function. We are also able to identify a financial intermediation shock, reflecting changes in the provision of credit by the banking system and the degree of financial liberalisation.

We demonstrate some of the practical uses to which the model can be put. These include: (a) estimating the deviation of each of the variables from long-run equilibrium to generate measures of the output gap and the size of liquidity under/overhangs; (b) analysing the importance of different shocks for each of the variables over different periods in UK economic history; and (c) generating conditional inflation forecasts based on different paths for the stochastic trends and monetary policy.

1 Introduction

In this paper we describe a small, structural empirical model of the UK monetary transmission mechanism, which can be used for policy analysis and forecasting. As with the companion analytical model project (see Dhar and Millard (2000)), our concern is with the role of money in the transmission mechanism, and so we focus on the interactions between nominal and real variables and their relationship with inflation. The model is very much in the spirit of the Bank of England's 'pluralist' approach to modelling and forecasting (see Bank of England (1999)). So even though we aim to develop a model in which the monetary channels of influence are spelled out directly, our small stylised model ignores many features of the real world that are of major importance to policy-makers, such as a detailed treatment of the labour market. We do this in order to focus on issues that are important to monetary economists.

Our methodological approach to forecasting informs the kind of model we want to construct. Specifically, we want to generate conditional forecasts, based on relatively few assumptions about economic primitives. By primitives we mean fundamental shocks, trends or forcing processes, which ultimately drive the endogenous variables. These fundamentals might include trend productivity growth, trend velocity growth and the nominal anchor. Our approach to forecasting is as follows: given assumptions about these primitives, and given our estimated model of the propagation mechanism, what is the conditional forecast of inflation?

A prerequisite therefore is that the model we use is structural, in the sense that we can assign economic meaning to the sources of uncertainty in our model.[(1)] A weakness of the large macro-model approach to forecasting is that the complexity and large number of sources of uncertainty in these models sometimes make it difficult to understand why certain results are generated. The model we develop is small, with eight endogenous variables, and we use theory-consistent criteria to identify eight economic shocks, of which four

(1) Note that this use of the word 'structural' differs slightly from that of the dynamic stochastic general equilibrium (DSGE) school, where the term refers to a model in which all parameters have economic interpretations in terms of primitives, such as preferences and technology.

have permanent effects on the endogenous variables and four have only temporary effects.

The relationship with previous work

We aim to build on previous work on monetary forecasting models. Perhaps the most influential of these is the 'P-Star' model, first applied in a US context by Hallman, Porter and Small (1991). This model in effect makes the quantity theory operational by inverting the equation of exchange to relate the trend price level (p^*) to trend velocity (v^*) and potential output (y^*). The actual price level is then assumed to adjust to this trend price level, according to an estimated distributed lag process.

Such a model is attractive because it accords the quantity theory a central role, but it is clearly non-structural. All the dynamics of the transmission mechanism are represented in the distributed lag process for prices and, more often than not, the estimates of trend velocity and potential output required to estimate p^* are purely statistical constructs, and hence difficult to interpret as economically meaningful concepts. The approach we adopt in this paper is somewhat different from the basic P-star framework. We expand the number of variables considered to a set that might be thought of as a minimal representation of the UK transmission mechanism. And then we use more general restrictions derived from economic theory to identify trends in velocity, output, the nominal anchor and other trends in a structural vector autoregression (VAR) containing all these variables.

We also aim to tie in our model with the work on monetary overhangs ('M-M*') previously carried out within the Bank (see Thomas (1997a,b,c)). This work estimated long-run money demand functions for different sectors in the economy, to produce estimates of monetary under/overhangs or liquidity gaps. While this work proved useful in identifying and calibrating the potential risks from strong monetary growth, it also showed that the dynamic interaction between money holdings, activity and prices was likely to depend on the shock that had hit the economy. In this paper we build on the M-M* work, by being able to show explicitly how the relationship between money, activity and prices differs according to which fundamental shock hits the economy. We are also able to construct different concepts of the liquidity gap, each of which may have a different link with output and inflation.

We also regard this paper as highly complementary to work on analytical models that embody temporary liquidity overhangs, as outlined in Dhar and Millard (2000). That project involves the construction of a dynamic stochastic general equilibrium (DSGE) model of the transmission mechanism, which aims at consolidating our understanding of the role of money. DSGE models, when linearised, can usually be written as a first-order vector autoregression. Consequently, the model developed in this paper can be thought of as the empirical counterpart to the DSGE model developed elsewhere.

The structure of the paper is as follows. In the next section, we describe our overall approach to modelling economic time series. It explains how we decompose the movements of the variables in our system into economically meaningful shocks, through placing sufficient restrictions on a statistical model of the data. In Section 3, we set up the system of variables to be modelled, and apply the techniques of Section 2 to obtain a representation of the variables in terms of the permanent and temporary structural shocks. The properties of the model are then examined through impulse response and variance decomposition analysis. Section 4 of the paper gives a demonstration of the practical uses of the model. This includes generating estimates of the deviation from trend for each variable (eg producing estimates of output gaps and liquidity overhangs); analysing the importance of different shocks as sources of movement for each of the variables over particular historical periods (we look at a number of case studies such as the appreciation of sterling 1979-81); and generating conditional forecasts, based on different assumptions about the future paths of the permanent and temporary shocks driving the system.

2 Modelling approach—how do we model time series movements?

In this section, we describe our general approach to modelling the time series we are interested in. In particular, we describe what we mean by the terms 'permanent' and 'temporary' shock and the terms 'trend' and 'cycle'. We also explain how we 'identify' them, ie give them an economic interpretation.

(a) Trends and cycles

We model our time series as the sum of two components, a trend and a cycle:

$$x_t = x_0 + \mathrm{F}\boldsymbol{t}_t + \Phi(\mathrm{L})v_t \qquad \textbf{(1)}$$

where

x_t = a vector of the n time series of interest at time t.

$\mathrm{F}\boldsymbol{t}_t$ = the non-stationary or permanent components of x_t, with $\boldsymbol{t}_t$ = the trends and F = loading matrix (ie how each trend affects each of the variables in the long run).

$\Phi(\mathrm{L})\, v_t$ = the stationary or temporary components of x_t, with v_t a vector of white noise disturbances, which generate dynamic or 'cyclical' effects through the distributed lag matrix $\Phi(\mathrm{L})$, where L is the lag operator ($\mathrm{L}^n v_t = v_{t-n}$). So $\Phi(\mathrm{L})v_t$ is a stationary distributed lag of current and past disturbances = $\Phi_0 v_t + \Phi_1 \mathrm{L} v_t + \Phi_2 \mathrm{L}^2 v_t$ ... or equivalently = $\Phi_0 v_t + \Phi_1 v_{t-1} + ...$

(b) Stochastic trends and permanent shocks

In addition to the usual deterministic growth or 'drift' term, we allow the trends to have a stochastic or random component, made up of a sequence of small random disturbances. Since these disturbances have a permanent effect on each of the variables, they are termed the 'permanent shocks'.

$$t_t = m + t_{t-1} + h_{1t} \tag{2}$$

or

$$t_t = m_t + \sum_{j=0}^{t} h_{1t-j} \tag{2a}$$

where m represents deterministic growth and h_{1t} are the permanent shocks. So our stochastic trends are simply a vector of random walks with drift. And the stochastic part of the trend is simply the sum of the current and past permanent shocks to hit the economy .(2)

Since our trends are stochastic, there is no reason to restrict the permanent shocks driving these trends from having cyclical effects (ie dynamic effects that differ from the long-run effects). So the vector v_t contains both permanent and temporary shocks:

$$v_t = [h_{1t}\ h_{2t}]'$$

where h_{2t} are purely temporary shocks, which do not have a long-run impact on x_t and so do not form part of the stochastic trends.

So in general, our trend-cycle model for x_t can be written in terms of the permanent and temporary shocks as:

$$x_t = x_0 + m_t + \mathrm{F} \sum_{i=0}^{t-1} h_{1t-i} + \Phi(\mathrm{L}) \begin{bmatrix} h_{1t} \\ h_{2t} \end{bmatrix} \tag{3}$$

where F is a n x k matrix, where k is the number of permanent shocks driving the system. Such a representation is often called a moving-average ('MA') representation, as it describes movements in x_t as a weighted moving average of current and past shocks.

(2) When the trends have a stochastic component, x_t is said to be a 'difference-stationary' rather than a 'trend-stationary' process.

(c) Alternative ways of modelling the trends

There are of course other ways of modelling the non-stationary components of our series. One obvious alternative is to model them as simple linear deterministic trends. In this case, the shocks in the model affect only the cyclical movements of each variable and are independent of the systematic forces driving the trends.

Another way of modelling the trends is as a sequence of one-off deterministic regime shifts:

$$t_t = m + m * D_t + t_{t-1} \quad \textbf{(4)}$$

$$t_t = m_t + m * \sum_{i=0}^{t} D_{t-i} \quad \textbf{(4a)}$$

where D is a vector of impact dummy variables and $\sum_{i=0}^{t} D_{t-i}$ a vector of one-zero step-dummies.

In this case, the non-stationarity of x_t is the result of a number of large relatively infrequent 'regime' shifts, rather than a sequence of successive small random changes.(3) This may be important for some of the trends we wish to identify. For example, the underlying nominal anchor or permanent component of inflation may be best modelled as a series of known shifts in the policy regime, rather than a sequence of small incremental changes. A similar argument may be used for modelling the trend in financial liberalisation.

In this paper, we attempt to model our stochastic trends without the aid of any deterministic regime shifts.(4) The statistical model we estimate later is relatively stable over the sample period, suggesting that it is reasonable to model the non-stationarity of our variables in terms of random walks with drift. But this is only weak evidence, and such a choice should not be based

(3) The dummy terms can be generalised to allow for shifts in the deterministic growth or drift term.

(4) Indeed we do not use any dummies in our system, even those that only generate temporary movements in the variables.

on empirical evidence alone. In future work we intend to compare the results below with results based on a system where at least some of the non-stationarity in the system is captured by deterministic regime shifts.

(d) Estimating a common trends model

The estimation of a model such as **(1)** proceeds by recognising that it is the inverse representation of a VAR model:

$$A(\mathrm{L})x_t = d + e_t \qquad \textbf{(5)}$$

where $A(\mathrm{L}) = A_0 + A_1\mathrm{L} + A_2\mathrm{L}^2...$

and the structural shocks that we ultimately recover, through the use of economic identifying restrictions, are simply a transformation of the VAR residuals e_t. For the moment, we leave the identification issue aside and proceed as if the VAR residuals, e_t, are equivalent to the economic shocks we wish to recover, denoted earlier as h_t. This is to focus attention on determining the number of permanent and temporary shocks driving the system. This has an important bearing on how we invert the VAR representation to yield an MA representation.

The number of permanent shocks depends upon the cointegrating properties of the data. Loosely speaking, two or more non-stationary variables are said to cointegrate if a linear combination of them is found to be stationary. In other words, the non-stationary or trend components of the variables tend to move together over time in some proportion, and the linear combination of the variables can be thought of as defining a long-run equilibrium relationship. This in turn implies that the non-stationary components of these variables are driven by a 'common' stochastic trend (or trends). The implication is that there are fewer stochastic trends or permanent shocks than there are endogenous variables. And the number of columns in the matrix $F = k < n$.

To see the duality between cointegration and the existence of common stochastic trends, we rewrite the VAR above in vector error-correction (VECM) form, where the long-run relationships between the levels of the variables in x_t are isolated in the matrix Π:

$$B(\mathrm{L})\Delta x_t = d + \Pi x_{t-1} + e_t \qquad \textbf{(6)}$$

If none of the variables cointegrate, then $\Pi = 0$, and we are left with a standard VAR in the first differences of the variables

$$B(\mathrm{L})\Delta x_t = d + e_t \qquad \textbf{(7)}$$

This, in most cases, can be easily inverted to yield the MA representation:

$$\Delta x_t = m + c(\mathrm{L})e_t \text{ where } c(\mathrm{L}) = B(\mathrm{L})^{-1} \qquad \textbf{(8)}$$

and rewriting in terms of trends and cycles

$$x_t = x_0 + m_t + C(1)\sum_{i=0}^{t-1} e_{t-i} + C^*(\mathrm{L})e_t \qquad \textbf{(9)}$$

where $C^*(\mathrm{L}) = (1-\mathrm{L})^{-1}[C(\mathrm{L}) - C(1)]$ and $C(1)$ is the long-run impact matrix equivalent to F above. In this case, the matrix F is an n x n matrix, and there are $k = n$ stochastic trends driving x_t.

If the variables are cointegrated with r cointegrating vectors or long-run relationships in the data, then rank $(\Pi)=r$ and Π can be written as $\Pi = ab'$, where b is an n x r matrix of r cointegrating vectors, and α is an n x r matrix of factor loadings. Inverting the VAR is more difficult in this case. We can still write the model as

$$x_t = x_0 + m_t + C(1)\sum_{i=0}^{t-1} e_{t-i} + C^*(\mathrm{L})e_t \qquad \textbf{(10)}$$

But this time, $C(1) = F$ is a reduced rank matrix (rank = n - r), which Engle and Granger (1987) and Engle and Yoo (1991) show can be written as the product of two matrices $C(1) = \gamma\theta¢$. γ and θ are n x n-r (or equivalently n x k) matrices related (non-uniquely) to the parameters of the cointegrating vectors a and b through the relationships $b¢\gamma = 0$ and $\theta¢a = 0$. In this case, the trend cycle decomposition of x_t should be written:

$$x_t = x_0 + mt + g\, t_t + C^*(\mathrm{L})e_t \qquad \textbf{(11)}$$

where there are *n-r* common stochastic trends (CSTs) given by:

$$\tau_t = \theta' \sum_{i=0}^{t-1} e_{t-i} \qquad \textbf{(12)}$$

So in general, when there are *r* cointegrating relationships among the *n* variables in x_t, the MA representation is defined in terms of $k = n\text{-}r$ common stochastic trends or permanent shocks and *r* temporary shocks.

Example: King, Plosser, Stock and Watson (KPSW) model (1991)

To see the duality between cointegration and common trends, consider the example in KPSW (1991).

x_t consists of consumption, investment and output:

$x_t = [\, con_t \; inv_t \; gdp_t \,]'$

KPSW suspect that consumption, investment and GDP are ultimately all driven by a single common stochastic trend — productivity. The 'great ratios' (ie $con_t - gdp_t$ and $inv_t - gdp_t$) are stationary, so that there are two cointegrating relationships between consumption and output and investment and output.

$$b' x_t = \begin{bmatrix} 1 & 0 & -1 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} con_t \\ inv_t \\ gdp_t \end{bmatrix} \qquad \textbf{(13)}$$

Given that there is one common stochastic trend, γ is a (*n* x (*n-r*)) matrix ie a (3x1) matrix:

$$\gamma = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \qquad \textbf{(14)}$$

And the trend-cycle decomposition is then given by:

$$\begin{bmatrix} con_t \\ inv_t \\ gdp_t \end{bmatrix} = \begin{bmatrix} con_0 \\ inv_0 \\ gdp_0 \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} t_t + c^*(L) \begin{bmatrix} \Delta t_t \\ e_{2t} \\ e_{3t} \end{bmatrix} \qquad \textbf{(15)}$$

(e) The identification issue

The identification issue refers to how we recover the structural shocks from the VAR residuals, which we put to one side in the above. It has a natural corollary with the identification of simultaneous equations models, except that we are putting restrictions on the MA rather than the VAR representation of the data. In the previous section, it was assumed that the residuals of the VAR and the structural shocks were the same. But the VAR is a reduced-form representation. Every variable is modelled on the lags of itself and the lags of other variables. So there are no contemporaneous relationships among the variables: A_0 in **(5)** and B_0 in **(6)** are simply the identity matrix. This implies two things for the reduced-form MA representation of x_t :

(a) only one shock affects each of the variables contemporaneously (C_0 is an identity matrix, so that e_{1t} only affects x_{1t} contemporaneously, e_{2t} only affects x_{2t} and so on); and

(b) the shocks are likely to be correlated, since any contemporaneous interaction among the variables will be captured in the variance-covariance matrix of the VAR residuals Σ.

In general, (a) and (b) are not properties we would want our structural shocks to satisfy. Ideally, we would want our structural shocks to be mutually uncorrelated, since we want them to represent distinct and independent economic processes. We also want them to satisfy certain theoretical criteria. So, for example, we might like to restrict some of the long-run properties of the shocks, leaving the contemporaneous effects to be determined by the data, rather than *vice versa*.

So as a first stage, we define a structural model as one that allows each shock to have a contemporaneous effect on each of the variables in x_t. This involves pre-multiplying the reduced-form VAR or VECM representation by a matrix, $A_0 = \Gamma_0^{-1}$ as in KPSW (1991), which in MA form for both cointegrated and non-cointegrated systems yields:

$$\Delta x_t = \Gamma(\mathrm{L})h_t = \Gamma(1)h_t + \Gamma^*(\mathrm{L})h_t \qquad \textbf{(16)}$$

where the variance-covariance matrix of the structural shocks is denoted Ω, and the relationship between the reduced-form and structural parameters is given by:

$$\mathrm{e_t} = \Gamma_0 h_{\mathrm{t}} \quad \text{and}$$
$$C(L) = \Gamma(L)\Gamma_0^{-1} \quad C(1) = \Gamma(1)\,\Gamma_0^{-1} \quad \Omega = \Gamma_0^{-1}\,\Sigma\,\Gamma_0 \qquad \textbf{(17)}$$

Note that this is merely a transformation of the reduced-form model. It places no testable restrictions on the data. In the simultaneous equations literature, if Γ_0 is appropriately defined, the model would be said to be 'just' or 'exactly' identified. So the key to identifying both the permanent and temporary shocks is to identify the matrix $\Gamma_{0,}$ since this is the link between the structural and reduced-form parameters. We can see from the relationships above that we can identify the elements of Γ_0 in several ways:

(i) We can place contemporaneous restrictions on the shocks eg preventing a shock from having a particular effect on a variable, because of known or assumed timing lags. This would imply restricting certain elements of Γ_0 to be zero.

(ii) We can place restrictions on the dynamic effects of the shocks. For example, we may wish to impose some cross-equation restrictions implied by the rational expectations hypothesis, though in general these are over-identifying (ie they do place testable restrictions on the data). Given that the reduced-form C(L) parameters are known, this would mean restricting the elements of Γ_0 so that the structural MA parameters $\Gamma(\mathrm{L}) = \mathrm{C(L)}\,\Gamma_0$ take a particular form.

(iii) We can place restrictions on the long-run impact of the shocks. This is often preferable to placing contemporaneous or dynamic restrictions on the shocks, as economic theory often has more to say about the long run. This would mean choosing Γ_0 so that $\Gamma(1)$ takes a particular form. Note that any cointegrating relationships will play an important part in this, since the matrix of long-run multipliers is of reduced rank and can be split into $\Gamma(1) = [F\ 0]$ satisfying $b'F = 0$ (see KPSW (1991) and Wickens (1996)).

(iv) Finally, we can place restrictions such that the variance-covariance matrix of the structural shocks takes a particular form. As argued earlier, we would want our structural shocks to be orthogonal to one another, and so we might want to place the restrictions that $\Gamma_0^{-1}\,\Sigma\,\Gamma_0 = \Omega = \text{I}$.

In this paper, we use a combination of restrictions (iii) and (iv) to identify the permanent shocks, and (i) and (iv) to identify the temporary shocks. In the presence of cointegrating relationships, KPSW (1991) and Warne (1991) show that Γ_0 can be partitioned into two matrices = $[H\ J]$, which allows us to break down the identification of Γ_0 into several stages:

(i) Cointegrating restrictions that determine the rank of H and J, and place some restrictions on the pattern of H. These impose $(n\text{-}r) \times r$ restrictions on Γ_0.

(ii) Identifying the permanent shocks. This involves orthogonality restrictions on the permanent shocks, as well as long-run restrictions. This provides $(n\text{-}r)^2$ restrictions (see Mellander *et al* (1992)).

(iii) Orthogonality between the permanent and temporary shocks. This imposes $r(n\text{-}r)$ restrictions.

(iv) Identifying the transitory shocks using orthogonality and contemporaneous restrictions. This provides r^2 additional restrictions.

In all, we impose n^2 restrictions on $\Gamma_{0,}$ which is the minimum we need to identify exactly its n^2 elements. Following KPSW (1991), we also place some testable over-identifying restrictions on the cointegrating vectors at stage (i). This is to ensure that our cointegrating vectors represent, as far as possible, sensible long-run equilibrium relationships. As we will see, this is useful in tying down some of the long-run multipliers.

3 Results

To estimate our structural monetary model, we consider a system of eight variables, all of which are thought to play a significant role in the monetary transmission mechanism of the UK economy.

- $m - p$: real M4 (break-adjusted nominal M4, deflated by the GDP market-price deflator)
- y : real GDP at market prices
- is : base rate
- il : long-term interest rates
- pk : real asset prices (FTSE All-Share index deflated by the GDP market-price deflator)
- Δp : Three-month annualised rate of seasonally adjusted RPIX inflation
- id : the weighted own-rate on M4 (a weighted average of bank and building society deposit rates)
- e : The real effective exchange rate (the nominal effective rate multiplied by relative unit labour costs; a rise in e represents a real appreciation).

The first six variables are fairly representative of those used in typical closed-economy monetary models of the transmission mechanism, see eg the model of Blanchard (1981), which examines the links between money, asset prices, bond yields and inflation in a rational-expectations framework. We augment these variables with the own-rate on M4 and the real exchange rate. This allows us to extend the basic closed monetary economy model to the case of a small open economy with a banking system.(5) Developments in the UK economy's relationship with overseas economies (eg changes in exchange rate regimes and trading relationships such as the common market) and changes in the structure and competitiveness of the banking system (eg the financial controls of the 1970s and the liberalisation of the 1980s) have been important influences on the UK economy over the past thirty years. So any empirical monetary model needs to encompass them. But this potentially

(5) See Dornbusch (1976) and Obstfeld and Rogoff (1996) for examples of small open-economy models, and Fischer (1983) and Dhar and Millard (2000) for models that incorporate a banking system.

adds to the number of stochastic trends driving the system, eg overseas demand and banking sector shocks.

Data for these variables exists over the period 1964 Q1 to 1998 Q2, which we use as our sample period. It is true that this sample period encompasses a number of potential regime shifts, such as the movement from fixed to floating exchange rates in 1972 and 1992. As discussed earlier, we attempt to model such changes as part of the stochastic trends (ie as one of a series of successive permanent shocks), rather than as large one-off events through the use of deterministic shift dummies. Tests of the stability of the estimated system give an idea of how reasonable this assumption is. But we intend to experiment with different ways of allowing for regime shifts in future work.

The estimation and analysis of our structural empirical model is carried out in several stages:

- *Cointegration analysis*. The unrestricted VAR system containing the levels of all the variables is estimated, and Johansen's (1988) ML procedure for determining the cointegrating rank of the system is applied. This is to determine the number of common stochastic trends in the system. We also place some (over)identifying restrictions on the cointegrating vectors as a first stage in identifying the shocks, although as argued by Warne (1991), this is not a necessity to identify a SVAR model.

- *Placing structural identifying restrictions on the shocks to obtain an SVAR model.* The reduced-form errors of the VECM system are transformed into structural shocks, using identifying restrictions on the short and long-run impact of the shocks as discussed earlier.

- *Impulse response analysis*. The dynamic impact of the identified shocks on each of the variables is analysed to see if the predictions are sensible.

- *Variance decomposition.* The importance of each of the permanent shocks in driving each variable in the system is examined, at different time horizons.

It is important to emphasise that the identifying restrictions we impose are not meant to be set in stone, especially as some of them are controversial and model-dependent. They are meant to illustrate what sort of restrictions can be imposed in this framework. In general, we can estimate the structural model using a variety of different identifying assumptions, and examine what difference it makes to the pattern of the structural shocks and their impact on each of the variables in the system.

(a) Cointegration analysis

Table A below shows the result of applying the Johansen (1988) ML procedure for determining the number of cointegrating vectors (CVs) and the corresponding number of common stochastic trends (CSTs) in the system. The determination of the cointegrating rank of the system will place restrictions on the matrix of long-run multipliers F, as described earlier. This is the minimum we need to do before imposing further restrictions on the MA representation of the model. But following KPSW (1991), it may be preferable to test some over-identifying restrictions on the cointegrating vectors before restrictions on the shocks themselves are imposed. This is because the estimated cointegrating vectors derived from the Johansen procedure are identified in an arbitrary manner and do not in general have an economic interpretation. So we also test whether the vectors can be restricted to conform to meaningful economic relationships.

Table A: Cointegration analysis

Unrestricted constant
Effective sample: 1965 Q3 to 1998 Q2: Lag(s) in VAR-model: 6
Obs.- no.of variables: 83

I(1) analysis

Eigenv.	L-max	Trace	H0: r	n-r	L-max90	Trace90
0.3864	64.47	212.39	0	8	32.26	149.99
0.3491	56.69	147.92	1	7	28.36	117.73
0.2397	36.18	91.24	2	6	24.63	89.37
0.1633	23.53	55.06	3	5	20.90	64.74
0.0971	13.48	31.52	4	4	17.15	43.84
0.0817	11.25	18.05	5	3	13.39	26.70
0.0470	6.35	6.80	6	2	10.60	13.31
0.0034	0.45	0.45	7	1	2.71	2.71

The test results indicate that there are probably four cointegrating vectors at the 10% significance level. This implies that there are four common stochastic trends driving the eight variables. Blanchard's (1981) closed-economy model has four central equilibrium relationships: a term-structure relationship, an asset pricing equation, a money demand equation and an aggregate demand relationship. This would suggest four cointegrating relationships: the spread between short rates and long rates (as the expectations hypothesis of the term structure suggests that short and long rates should be equal in the long run); an asset price relationship linking real asset prices homogeneously with income and negatively with real interest rates; a money-demand relationship linking real money with income, real asset prices (as a proxy for real wealth), and the opportunity cost of holding money; and an aggregate demand relationship linking GDP to wealth, interest rates and the exchange rate.

Table B below shows the results of restrictions tests on the CVs that examine whether they conform to the equilibrium relationships implied by the Blanchard model. At least four restrictions in each equation are needed to identify the vectors (see Johansen and Juselius (1994), Pesaran and Shin (1995)). The initial restrictions we imposed were as follows:

(i) The first vector was restricted to form a money-demand relationship. This involved imposing zero restrictions on all variables except money, GDP and asset prices, and restricting the deposit rate and base rate to form a term in the opportunity cost of holding money (*id-is*).

(ii) The second vector was restricted to form a term-structure relationship. So the coefficients on short and long rates were restricted to be equal with opposite sign, and all other coefficients were restricted to be zero.

(iii) The third vector was restricted to be an asset-price relationship. So the coefficients on income and asset prices were restricted to be equal in magnitude with opposite sign, as were the coefficients on the short-term interest rate and inflation. All other coefficients were restricted to be zero.

(iv) The fourth vector was restricted to be an aggregate demand relationship. For this we excluded real broad money (no wealth effect as it largely represents inside money) and restricted two of the three interest rate coefficients to be zero, leaving the other interest rate to take up the burden of affecting aggregate demand. The results were broadly the same whichever two interest rates were excluded (partly owing to the restrictions already imposed on the short and long rates in (ii)).

Table B: Testing restrictions on the cointegrating vectors

***Hypothesis 1**: Money demand relationship, term structure, asset price equation, aggregate demand*

The LR test, $\chi^2(8) = 17.49$, p-value = 0.03

b'

is	*Il*	*m*	*y*	*pk*	*p*	*e*	*Id*
10.99	0.00	1.00	-1.31	-0.28	0.00	0.00	-10.99
1.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	-0.01	0.01	-1.00	0.00	0.00
0.00	0.00	0.00	1.00	-0.44	11.86	-0.37	-17.06

a	**Loading coefficients**				***t*-values**			
Dis	0.02	-0.33	-0.56	-0.04	1.04	-2.45	-2.88	-2.50
Dil	-0.03	0.16	-0.01	0.01	-2.05	1.79	-0.04	1.00
Dm	-0.07	0.22	0.03	0.02	-3.06	1.49	0.15	0.87
Dy	-0.02	-0.19	0.01	0.00	-1.00	-1.53	0.07	0.20
Dpk	-0.14	0.70	3.68	0.23	-0.84	0.63	2.35	1.77
Dp	0.10	-0.80	0.13	-0.03	1.77	-2.08	0.25	-0.69
De	-0.31	1.66	2.97	0.25	-4.26	3.50	4.42	4.61
Did	0.00	-0.10	0.03	0.00	0.03	-1.10	0.24	0.29

Table B: (continued)

Hypothesis 2: Money demand relationship, term structure, real interest and asset price equation

The LR test, χ (9) = 17.84, *p*-value = 0.04

b'

Is	*il*	*m*	*y*	*pk*	*p*	*e*	*id*
1.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00	-0.00	-1.00	0.00	0.00
10.92	0.00	1.00	-1.34	-0.25	0.00	-0.00	-10.92
0.00	0.00	0.00	-2.71	1.00	-36.08	1.14	52.02

a	**Loading coefficient**				***t*-values**			
Dis	-0.34	-0.55	0.02	0.01	-2.48	-2.87	1.05	2.49
Dil	0.16	-0.01	-0.03	0.00	1.77	-0.04	-1.97	-0.99
Dm	0.22	0.03	-0.07	-0.01	1.49	0.15	-3.09	-0.87
Dy	-0.19	0.01	-0.02	0.00	-1.50	0.04	-1.00	-0.19
Dpk	0.73	3.65	-0.15	-0.07	0.66	2.34	-0.89	-1.78
Dp	-0.78	0.12	0.10	0.01	-2.04	0.22	1.73	0.69
De	1.66	2.95	-0.32	-0.08	3.51	4.42	-4.28	-4.62
Did	-0.10	0.03	0.00	0.00	-1.13	0.26	0.03	0.30

The first vector was normalised on broad money, the second and third on the base rate and the fourth on output. This normalisation, together with the restrictions in (i) to (iv), amounted to 24 restrictions in total, eight of which are over-identifying.

As can be seen in Table B the χ^2 test indicates that these over-identifying restrictions (collectively labelled 'Hypothesis 1' in the table) are on the borderline of acceptability at the 5% level. The money-demand and term-structure relationships are both well-defined, with sensible coefficients and loading vectors. Interestingly, the loading vectors suggest that the money cointegrating vector (which can be interpreted as the deviation of actual from long-run equilibrium money holdings, M-M*, the liquidity overhang) has a positive effect on inflation and a negative effect on the real exchange rate. This suggests that the liquidity overhang, on this definition, may have an important part to play in the transmission mechanism.

An important caveat here is that the relationship we have estimated for money holdings is highly aggregated, and uses real asset prices as a proxy for wealth. Previous work in the Bank (Thomas (1997a) and (1997b) and Brigden and Mizen (1999)) suggests that liquidity overhangs are best estimated at a sectoral level, since different agents (eg households, industrial and commercial companies, and financial companies) have different motives for holding money. This would imply different elasticities on activity and wealth for each sector's demand-for-money relationship. So the aggregate relationship estimated here may mask important sectoral differences. We discuss the concept of the monetary overhang further in Section 4 of this paper.

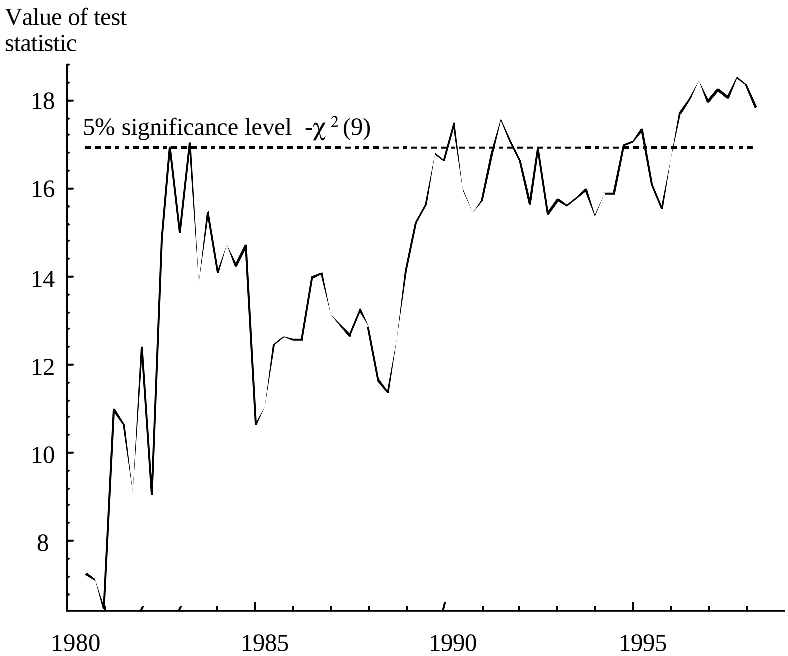
The other cointegrating vectors, however, are not well-defined under Hypothesis 1. In particular, the coefficients on income and asset prices are extremely low in the third identified vector, suggesting that the real short-term interest rate is close to being stationary. This would be plausible for a small economy if the world real interest rate was also stationary over the sample period. And a stationary real interest rate is also appealing for other theoretical reasons (see Rose (1988)). Also, the coefficients on interest rates and the exchange rate in the aggregate demand relationship are wrongly signed. So it seemed sensible to restrict the third cointegrating vector to be a stationary real interest relationship, and normalise the fourth vector on asset prices to see if this produced an appropriate asset price relationship.

These restrictions, summarised in Hypothesis 2 in Table B, are slightly more acceptable. But the resulting asset price relationship is not well-defined. In particular, the coefficient on income is well above one, and could not be restricted. Also, the terms in the interest rate and inflation could not be restricted to form a real interest rate term, leaving real asset prices dependent on the rate of growth of nominal variables in the long run.(6) Interestingly, real asset prices are significantly related to the real exchange rate. This is not surprising, since the equity price index we use (the FTSE All-Share index) contains quoted companies, some of which have a strong international exposure and some of which are partly owned by the overseas sector.

One reason why these restrictions might have been rejected at conventional levels of significance is that our sample period ends at a cyclical peak. For example, in the eight quarters leading up to 1998 Q2 both asset prices and the real exchange rate rose very strongly. To check for this possibility, we looked at the stability of these long-run relationships over different sample periods. The over-identifying restrictions test was computed recursively over progressively larger samples, starting with the period 1965 Q3-1980 Q1, and shifting the end of the sample forward one quarter at a time. Chart 1 shows the recursive χ^2 test statistic relative to its 5% significance level. The restrictions appear to be acceptable at the 5% level for every sample except those ending in the last few quarters leading up to 1998 Q2. And the restrictions are never rejected at the 1% level. This might suggest that our sample period has ended at a cyclical peak, and that in future periods the variables should start to return to their long-run equilibrium values implied by the four CVs we have identified.

(6) Note that we use the deposit rate as the relevant interest rate in this equation. This avoids certain problems with the rank condition of identification that would arise if we used the short rate or long rate and attempted to restrict them to form a real interest rate term with inflation.

Chart 1: Recursive over-identifying restrictions test



But of course, it could equally reflect our failure to place sensible identifying restrictions on the CVs, in particular on the asset price relationship. To test this, we estimate a closed-economy system that excludes the real exchange rate from the system. Here, the cointegration analysis suggested that there was less evidence of a fourth vector. And as none of them contains the real exchange rate, we tested whether the first three CVs of our open-economy system were acceptable in the closed-economy system. The implied over-identifying restrictions could not be rejected at the 5% level, and the sum of the coefficients on output and asset prices in the money equation could be restricted to one (*p*-value 0.09). So given the rule that cointegrating vectors that are acceptable in a sub-system should also be cointegrating vectors in a larger system, this suggests that the asset-price relationship in the open-economy system is the reason why the over-identifying restrictions test is only marginally acceptable.

Given their broad acceptability over time and in smaller sub-systems (and also remembering that we have not added any dummy variables to our system), we take the CVs we have identified as reasonably acceptable long-run relationships. But in our subsequent analysis, we point out where the asset price relationship might be having an impact on the results.

(b) Placing identifying restrictions on the shocks

Following the cointegration analysis, the next stage is to estimate the VECM representation (equation **(6)** above) with the cointegrating rank and the restrictions on the CVs imposed. Despite having some doubts about the identification of the cointegrating vectors in Section (a), the estimated VECM has reasonably good statistical properties. Table C below shows some diagnostic tests on the VECM. The only major statistical problems are with the normality of the residuals of the inflation and real money equations. An inspection of the residuals shows that this is largely related to the large hike in VAT in 1979 Q3, which had the temporary effect, over one quarter, of raising inflation and reducing real balances. An appropriate dummy variable for this period is a possible solution. But for now we stick to our initial strategy, which is to attempt to model our system of variables without the aid of any deterministic variables. So this VAT effect will be captured in one of our identified shocks.

The VECM also seems to be a reasonably stable statistical model. Chart 2 shows recursive one-step (labelled 1up) and break-point (labelled Ndn) Chow test statistics for each equation in the system (relative to their 5% significance level), as well as a test for the system as a whole. None of the equations appears to show any major sign of a structural break (except perhaps, unsurprisingly, the real exchange rate over the ERM period), which implies that our attempt to capture the non-stationarity in our system via the stochastic trends is not entirely unreasonable.

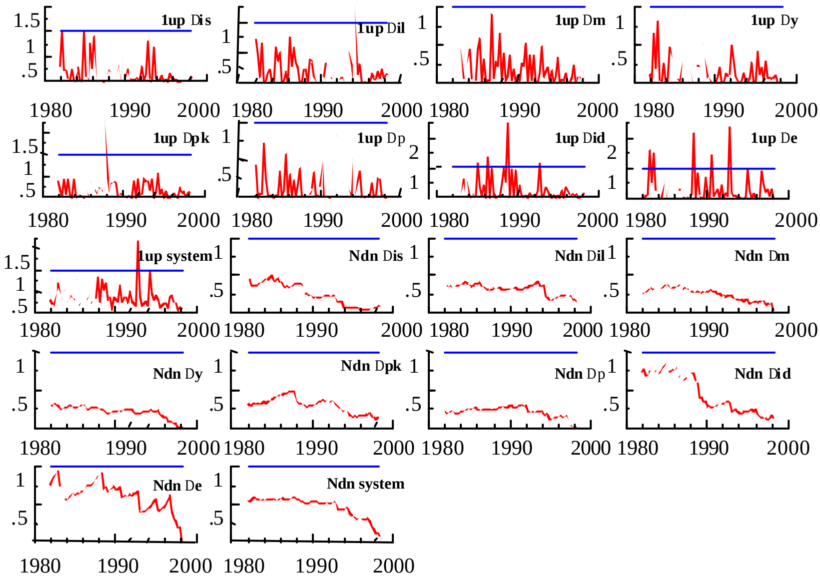
Table C: Diagnostic tests on the VECM

Dis:	AR 1-5 F(5, 81)	=	0.8158	[0.5419]
Dil	AR 1-5 F(5, 81)	=	2.0097	[0.0859]
Dm	AR 1-5 F(5, 81)	=	0.4872	[0.7849]
Dy	AR 1-5 F(5, 81)	=	1.9378	[0.0970]
Dpk	AR 1-5 F(5, 81)	=	0.5315	[0.7518]
Dp	AR 1-5 F(5, 81)	=	0.9929	[0.4274]
Did	AR 1-5 F(5, 81)	=	0.3936	[0.8519]
De	AR 1-5 F(5, 81)	=	0.6244	[0.6816]
Dis	normality χ^2 (2)	=	3.2922	[0.1928]
Dil	Normality χ^2 (2)	=	1.1320	[0.5678]
Dm	Normality χ^2 (2)	=	10.142	[0.0063]**
Dy	Normality χ^2 (2)	=	1.211	[0.5458]
Dpk	Normality χ^2 (2)	=	8.2118	[0.0165]*
Dp	Normality χ^2 (2)	=	15.552	[0.0004]**
Did	Normality χ^2 (2)	=	5.2903	[0.0710]
De	Normality χ^2 (2)	=	3.6641	[0.1601]
Dis	ARCH 4 F(4, 78)	=	0.0775	[0.9889]
Dil	ARCH 4 F(4, 78)	=	0.5862	[0.6736]
Dm	ARCH 4 F(4, 78)	=	0.3639	[0.8336]
Dy	ARCH 4 F(4, 78)	=	1.8822	[0.1219]
Dpk	ARCH 4 F(4, 78)	=	0.1283	[0.9717]
Dp	ARCH 4 F(4, 78)	=	0.1991	[0.9381]
Did	ARCH 4 F(4, 78)	=	0.3764	[0.8249]
De	ARCH 4 F(4, 78)	=	0.4654	[0.7609]
Vector	AR 1-5 F(320,324)	=	1.0939	[0.2105]
Vector	Normality χ^2 (16)	=	42.959	[0.0003]**

Notes: AR 1-*r* is the Lagrange multiplier test for *r*th-order residual autocorrelation; normality is the test of Doornik and Hansen (1984), which tests whether the skewness and kurtosis of the residuals corresponds to those of a normal distribution; ARCH is a test of autoregressive conditional heteroscedasticity described in Engle (1982); Xi^2 is the test for heteroscedasticity of White (1980). P-values are in parentheses, a ' *', and ' **' reflect a rejection of the null hypothesis at the 5% and 1% levels respectively.

Chart 2: Stability tests on the VECM

1 = 5% significance level



Identifying the permanent shocks

Given that our statistical model seems relatively stable, we now attempt to place some economic restrictions on the system. As discussed earlier, the restrictions we impose are purely illustrative. Different identifying assumptions or a different labelling of the shocks we identify may be more appealing to some. The framework we have adopted is meant to be flexible, so that the implications of different identifying assumptions can be examined straightforwardly. To place identifying restrictions on the shocks, we first invert the VECM to yield the MA representation of the data (where the variables are described as a function of current and lagged reduced-form shocks) described earlier. We then place restrictions on the impact of shocks, according to chosen economic criteria.

As discussed in Section 2, we need to place $(n\text{-}r)^2$ restrictions to identify the permanent shocks. Ten of the restrictions can be obtained by assuming that the structural permanent shocks are mutually uncorrelated (ie originate from independent sources) and have a normalised variance of 1. This leaves six further restrictions to be imposed. As discussed earlier, we impose long-run restrictions on the impact of the CSTs based on the predictions of theory.

So what type of permanent shocks should we be looking for, and how do we identify them? Some guidance on this is offered by the cointegration analysis we carried out earlier. Indeed, it is important that the restrictions we impose are consistent with the cointegrating vectors we identify. The fact that we have found cointegrating relationships for money demand, the term structure, real interest rates and asset prices suggests that we should rule out identifying our permanent shocks as those to money demand, the term and equity risk premia, or the world real interest rate. Consider the term-structure relationship. The cointegrating vector implies that short and long rates move together in the long run. In contrast, the existence of a permanent term-premium shock (and hence the existence of a term-premium stochastic trend) would imply that short and long rates moved apart over time. So the two are inconsistent. A similar argument applies to the other relationships.

This leaves us with several potential candidates for the four fundamental permanent shocks:

(1) Domestic productivity/aggregate supply shocks.

(2) Domestic demand shocks, such as shifts in fiscal policy and consumer preferences.

(3) A permanent nominal shock, reflecting the implicit inflation/money growth target of the authorities. In the absence of full credibility, this might be interpreted as the trend in inflation expectations or ‘core’ inflation.[7]

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(7) There are obvious Lucas critique issues here since a shift in the nominal target of the authorities might influence the process which agents use to generate their expectations. This would invalidate the assumption of constant parameters in the structural MA representation of the system.

(4) A financial liberalisation/credit market shock, which affects the competitiveness/willingness to lend of the banking system and leads to a permanent shift in the velocity of circulation. Another way to think of this is as a shock to the demand and supply of the intermediation services provided by banks.

(5) Shifts in the pattern of foreign demand and supply, which affect the equilibrium current account.

Given that the real interest rate is stationary, we choose not to identify the aggregate demand shock as one of our permanent shocks. So we assume that shifts in aggregate demand have no long-run effects on any of the variables of our system. This is controversial, since in certain open-economy models a shift in aggregate demand will affect the equilibrium real exchange rate in the long run. The typical mechanism is that, for a given level of equilibrium output in the long run, a rise in real domestic demand must be offset by a fall in net external demand, which is engineered through a rise in the real exchange rate.

But this argument only considers the internal balance of the economy, and ignores the fact that a current account deficit will result from a shift between domestic and overseas demand. The resulting fall in net external assets will continue to have negative wealth effects on domestic demand, as long as the deficit persists. Provided that the propensity to consume out of wealth is greater than the real rate of return on overseas assets and that the economy is small relative to the rest of the world, the current account will return to balance at the initial level of the real exchange rate.[(8)] So in the long run, stock and flow equilibrium implies that a shift in any of the components of domestic demand will be offset by a wealth-induced fall in domestic consumption, rather than an exchange rate-induced fall in overseas demand. And as this does not affect the equilibrium level of output or the equilibrium current account, it should have no effect on the real exchange rate.

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(8) If the propensity to consume out of wealth is lower than the real interest rate, the model can become unstable, since the decumulation of assets/accumulation of debt will worsen the debt-service component of the current account faster than it improves the trade balance component.

So we identify the four permanent shocks on the following basis:

- The first shock is identified as a productivity shock (labelled an AS shock) and is restricted to have no long-run impact on the rate of inflation, although it may have cumulative effects on the price level. This shock is also intended to cover shocks to productivity from overseas such as oil shocks, and shocks emerging from the labour market.

- The second shock we identify as a shock to financial intermediation (labelled FIN). This is left unrestricted, as it is a shock for which we have few theoretical priors regarding its long-run effects. Potentially, a shift in the supply of credit could affect long-run output via 'credit-channel' effects on investment. And we would want such a shock to have a significant long-run effect on the opportunity cost of holding money; eg the spread between deposit rates and base rates would be expected to narrow as a result of a financial liberalisation.

- The third shock is identified as a nominal shock (NOM) and is restricted to have no impact on real output or the real exchange rate in the long run. We allow it to have an effect on real balances and real asset prices, given that a rise in core inflation is likely to affect the opportunity cost of holding M4 (since a small proportion of M4 is non interest bearing) and given that one of our cointegrating vectors suggested that the growth of nominal variables affects real asset prices in the long run.[9]

- The fourth shock is identified as a relative foreign demand (FOR) shock that permanently affects the equilibrium real exchange rate. It is restricted to have no long-run impact on output, inflation or any of the domestic interest rates (this only involves three restrictions, since the stationarity of the real interest rate and the term structure implies that anything that has a zero long-run effect on inflation also has a zero effect on the short and long-term interest rates). The first of these restrictions is somewhat controversial, as it implies that even though the real exchange rate changes in the long run, this has no long-run effect on the equilibrium level of output. Thus, we are assuming that in the long run

(9) If we did restrict the inflation rate to have no effect on asset prices, then the nominal shock would have to affect one or more of the other variables in the asset-price cointegrating vector to ensure consistency.

there are no wedge effects that drive a permanent gap between real product and consumption wages and that would in turn shift the NAIRU.

So the matrix of long-run multipliers F takes the form:

$$\begin{bmatrix} m-p \\ y \\ is \\ il \\ pk \\ p \\ id \\ e \end{bmatrix} = \begin{bmatrix} * & * & * & * \\ * & * & 0 & 0 \\ * & * & * & * \\ * & * & * & * \\ * & * & * & * \\ 0 & * & * & 0 \\ * & * & * & 0 \\ * & * & 0 & * \end{bmatrix} \begin{bmatrix} h_{AS} \\ h_{Fin} \\ h_{Nom} \\ h_{For} \end{bmatrix}$$

But of course some of the '*'s are restricted by the structure of the cointegrating vectors. As mentioned above, the real interest rate and term-structure CVs imply that shocks that are restricted to have a zero effect on inflation will also have a zero effect on both interest rates.

Identifying the temporary shocks

The restrictions we have imposed so far are enough to identify the common stochastic trends, but we need additional restrictions to carry out impulse response and variance decomposition analysis of the system. As a minimum, we need further restrictions to ensure that the temporary shocks are uncorrelated with the permanent shocks. But more importantly, we also want to give some economic interpretation to the temporary shocks. Potential candidates for the temporary shocks were suggested by the cointegrating vectors, eg risk-premium shocks.

Earlier, we also ruled out domestic demand shocks from having a permanent effect on any of the variables. But they may be an important influence in the short run. Perhaps more importantly, we have only identified the permanent component of monetary policy—the underlying inflation target (or agents' inflation expectations). But policy may also be subject to temporary disturbances due to policy errors, or because the authorities place some weight on information variables that are extraneous to our system of variables. This might explain part of the unexplained component of interest rate movements. To see how the permanent and temporary policy shocks interact, imagine that the authorities on average operate a Taylor rule:

$$is_t = r^* + p^*_t + a\,(p_t - p^*_t) + (1- a)\,(y_t - y^*_t) + h_{tpol}$$

$$p^*_t = p^*_{t\text{-}1} + h_{Nom}$$

The temporary policy shock h_{tpol} then represents any movement in interest rates that deviates from this rule. The permanent policy shock, as discussed earlier, permanently changes p^*, which changes is_t one for one in the long run (keeping the real interest rate unchanged at r^*), but less than one-for-one in the short run.

To identify the temporary shocks, we impose contemporaneous restrictions. In addition to the ten restrictions required for orthogonality, we must place six additional restrictions on the temporary disturbances to identify them. Unfortunately, these contemporaneous restrictions require us to make assumptions about the timing relationships between the variables. In particular, we are forced to take a stand on such issues as the degree of nominal rigidity in response to different shocks. The four shocks we attempt to identify and the restrictions we impose are as follows:

(i) A temporary monetary policy shock (labelled TPOL). On the basis of there being a lag between interest rate movements and demand, and a further lag (because of nominal rigidities) between demand and inflation, this shock is restricted to have no contemporaneous impact on output or inflation.

(ii) A domestic demand (AD) shock. This is allowed to have a contemporaneous effect on output, as it is not subject to the first lag mentioned in (i), but no contemporaneous effect on inflation, as it is subject to the second lag.

(iii) A foreign exchange risk-premium shock (FRP). This we interpret as a general shift in preferences towards sterling-denominated assets. Again we appeal to timing lags, and this shock is restricted to have no initial effect on output, prices and additionally the deposit rate, reflecting the stickiness of bank deposit-rate setting, although this last restriction is rather arbitrary.

(iv) The fourth temporary shock is left as unrestricted. For now, we label it a shock to the term premium (TERM), which drives a temporary wedge between the path of expected future short rates and the long-term rate of interest.

So in total, we impose the following restrictions directly on the contemporaneous impact matrix of the shocks Γ_0:

$$\begin{bmatrix} m-p \\ y \\ is \\ il \\ pk \\ p \\ id \\ e \end{bmatrix} = \begin{bmatrix} * & * & * & * & * & * & * & * \\ * & * & * & * & 0 & * & 0 & * \\ * & * & * & * & * & * & * & * \\ * & * & * & * & * & * & * & * \\ * & * & * & * & * & * & * & * \\ * & * & * & * & 0 & 0 & 0 & * \\ * & * & * & * & * & * & 0 & * \\ * & * & * & * & * & * & * & * \end{bmatrix} \begin{bmatrix} h_{AS} \\ h_{Fin} \\ h_{Nom} \\ h_{For} \\ h_{Tpol} \\ h_{AD} \\ h_{RP} \\ h_{Term} \end{bmatrix}$$

The sum total of our orthogonality restrictions (involving $n(n+1)/2=36$ restrictions), cointegrating restrictions ($r(n-r)=16$ restrictions), 6 restrictions on the permanent shocks and 6 on the temporary shocks is enough to identify uniquely the 64 elements of the impact matrix Γ_0, which transforms the reduced-form residuals into structural disturbances.

(c) Impulse response analysis

We are now in a position to analyse the dynamic effects of the identified structural disturbances on each of the variables. This provides a good indication of whether the identified shocks live up to the labels we have given them. Charts 3-10 show the effect of a one standard deviation shock for each of the identified permanent and transitory shocks.

The permanent shocks

- The effects of an AS shock conform almost exactly to theory. Real money, output, and asset prices all rise in the long run, following a supply shock. And real asset prices initially show a tendency to overshoot their long-run equilibrium. Also, there is a negative short-run effect on inflation, so that the price level falls permanently in response to an AS shock. The real exchange rate declines in the long run[10]. The liquidity gap, M-M*, declines initially, as income and asset prices both raise M* by more than the rise in M. So under an AS shock, M-M* is negatively associated with output, but positively associated with inflation.

- The effects of a nominal shock also look sensible. Short rates fall in the short run, the real exchange rate depreciates in line with traditional Dornbusch overshooting models and inflation rises. As this shock ultimately has a permanent effect on inflation, long rates rise in anticipation, so the term structure becomes upward-sloping. In the long run, all three nominal variables converge on the same value as implied by the stationary real interest rate. Money, real asset prices and output are both positively affected in the short run, before tailing away to zero. The chart shows that it is a good idea to restrict the cointegrating vectors before identifying the shocks. The imposition of the term structure and stationary real interest rate cointegrating relationships ensures that all three nominal variables are equated in the long run, in accordance with the Fisher hypothesis. Initially, M falls slightly below M*, despite a positive effect on real balances in the short run. But after around five quarters, a large liquidity gap emerges, which peaks at around the same time as output and a little ahead of inflation.

- The financial intermediation shock has a large impact on money balances, and deposit rates rise relative to short and long rates, implying a fall in the cost of intermediation. Output rises, and both inflation and the real exchange rate fall in the long run, which is perhaps suggestive of credit-channel effects on aggregate supply. M-M* falls in the short run, as rises in output, asset prices and the spread of deposit rates over short rates all work to increase M*. So under this shock, M-M* is negatively related to output in the short run, but positively related to inflation. The latter may simply result from not restricting the responses of nominal

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[10] In theory the real exchange rate declines to boost net trade sufficiently so that it meets the rise in import demand resulting from the wealth/income generated by the productivity increase.

variables to this shock to be zero.

- The chief impact of the foreign shock in the long run is on the real exchange rate. But there is also a negative effect on real asset prices, as implied by the asset-price relationship that we identified as one of the cointegrating vectors.

The temporary shocks

- The temporary monetary policy shock produces broadly sensible responses. It involves a cut in short-term interest rates, which increases asset prices and subsequently output and inflation in the short to medium term. So there is no 'price puzzle' effect. But the exchange rate initially shows a perverse response. Only after several quarters does it depreciate below its long-run equilibrium level as in the Dornbusch overshooting story. M-M* rises under this shock, as theory would predict. And (partly by construction) it leads both output and inflation with a positive effect.

- The responses to a domestic demand shock all accord with theory. An expansion of aggregate demand initially leads to a rise in interest rates by the authorities (eg since this produces inflation inconsistent with the authorities policy objectives) and a rise in output and the real exchange rate in the medium term.

- The impact of the foreign risk-premium shock appears to be sensible, having strong effects on real asset prices and the real exchange rate, consistent with it representing a shift in preferences towards sterling-denominated assets.

- The unrestricted shock, which we provisionally labelled a 'term-premium' shock, would seem to live up to its name. A fall in the premium leads to long rates falling relative to short rates, and this boosts money, output, asset prices and inflation in the short run.

Generally, the impulse responses are sensibly signed and provide some support for our identifying restrictions. In particular, neither of our monetary policy shocks exhibits the price puzzle problem. More interestingly, different shocks produce different relationships between surplus liquidity and output and inflation.

Chart 3: Aggregate supply shock impulse responses (% from base unless otherwise stated)

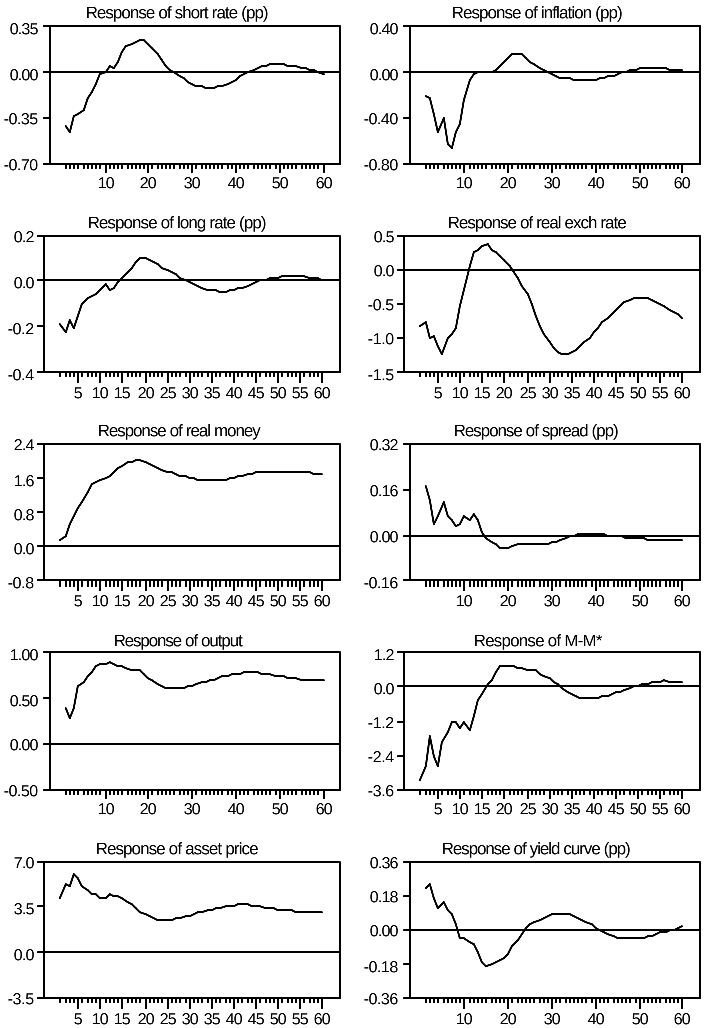


Chart 4: Financial liberalisation shock impulse responses (% from base unless otherwise stated)

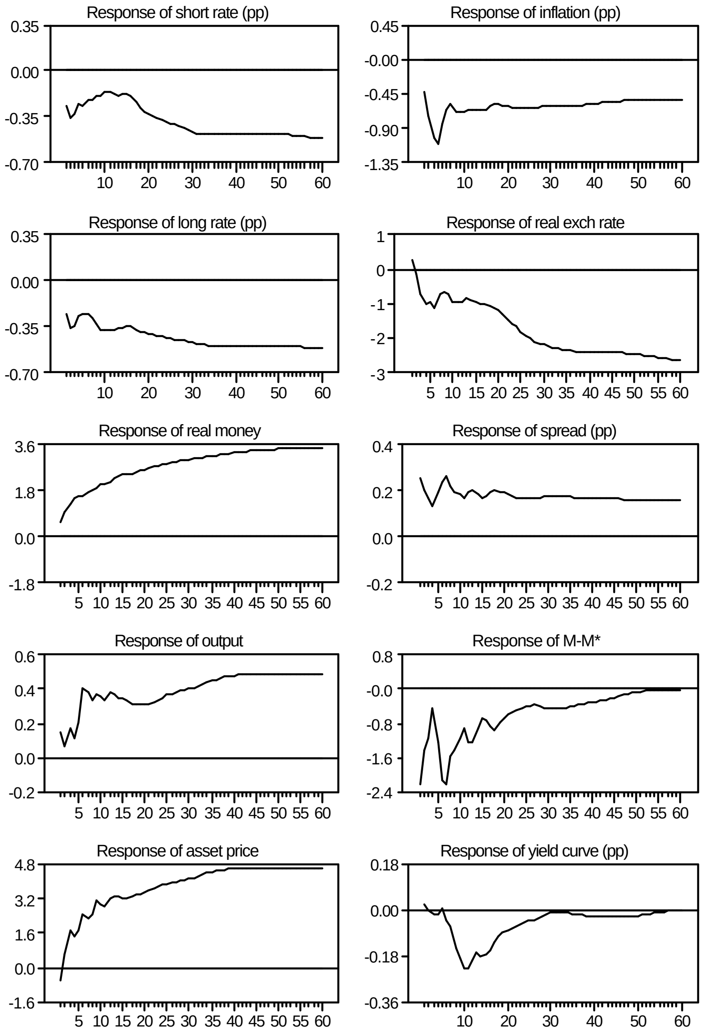


Chart 5: Permanent policy shock impulse responses (% from base unless otherwise stated)

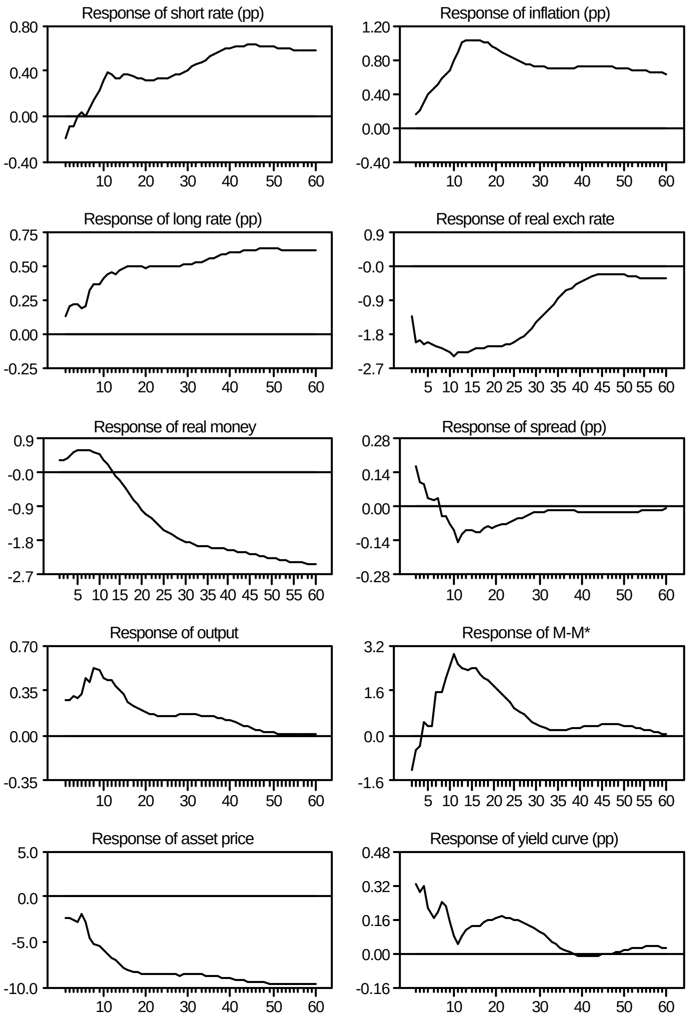


Chart 6: Relative foreign demand shock impulse responses (% from base unless otherwise stated)

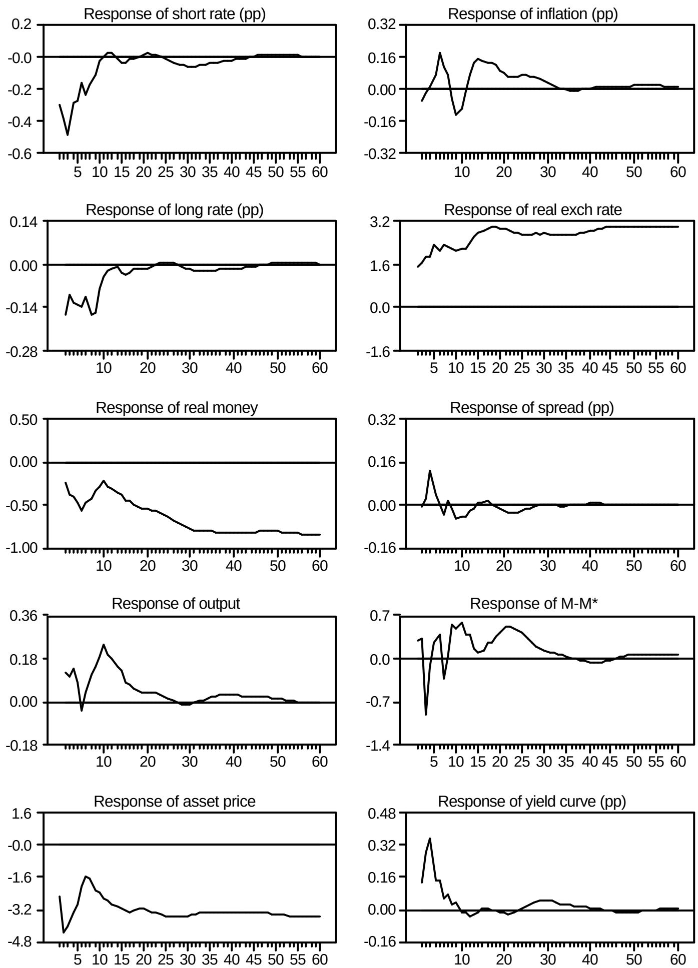


Chart 7: Temporary policy shock impulse responses (% from base unless otherwise stated)

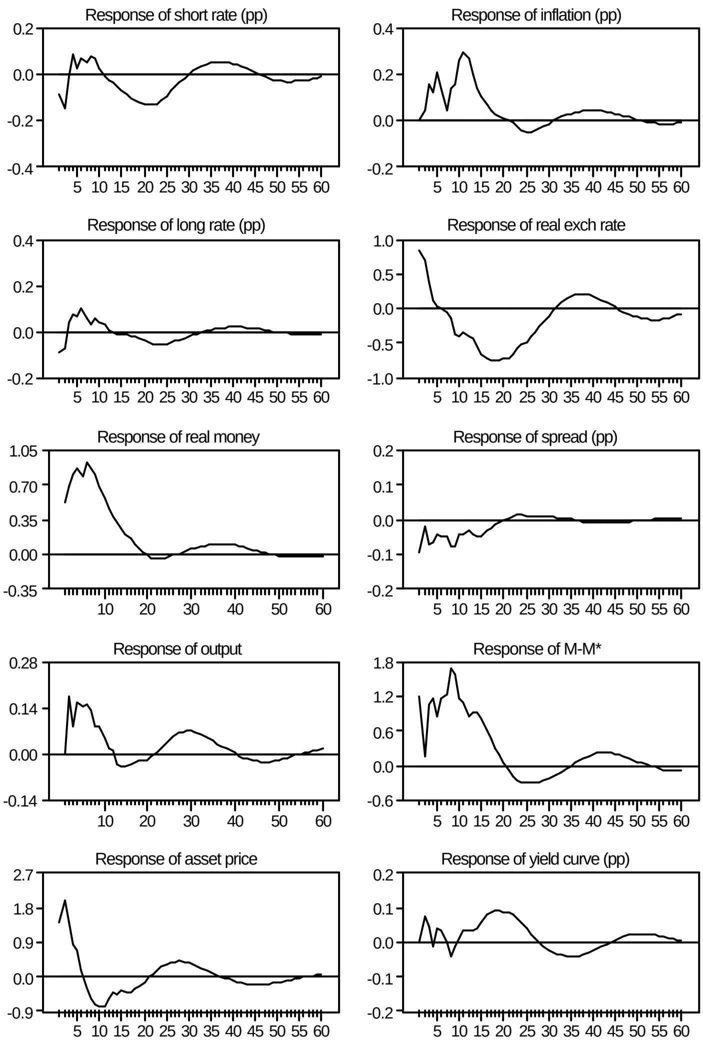


Chart 8: Foreign risk premium shock impulse responses (% from base unless otherwise stated)

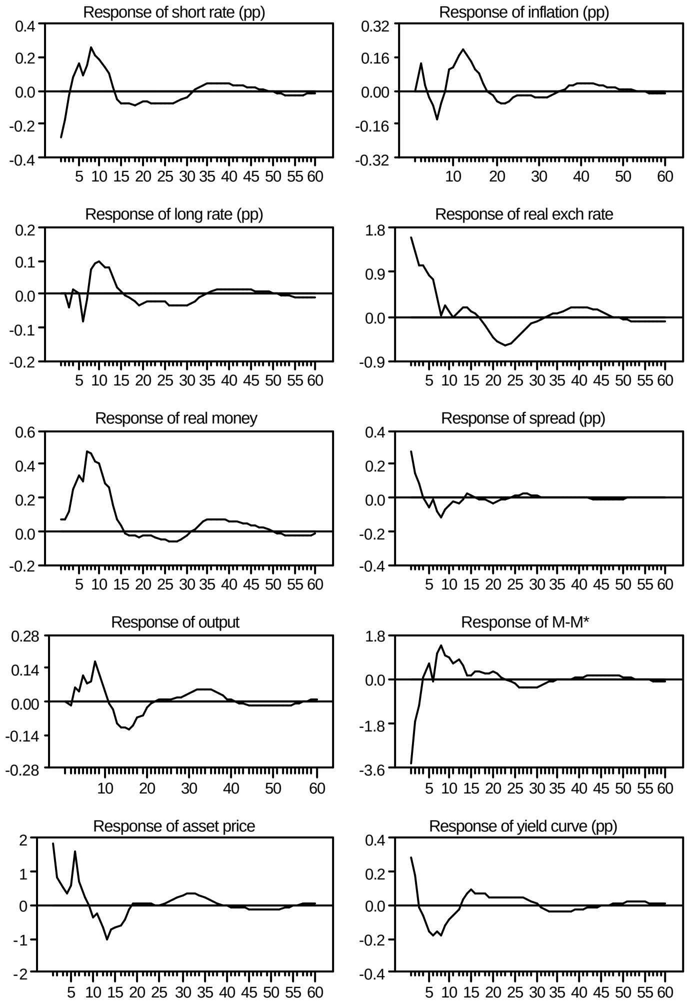


Chart 9: Term premium shock impulse responses (% from base unless otherwise stated)

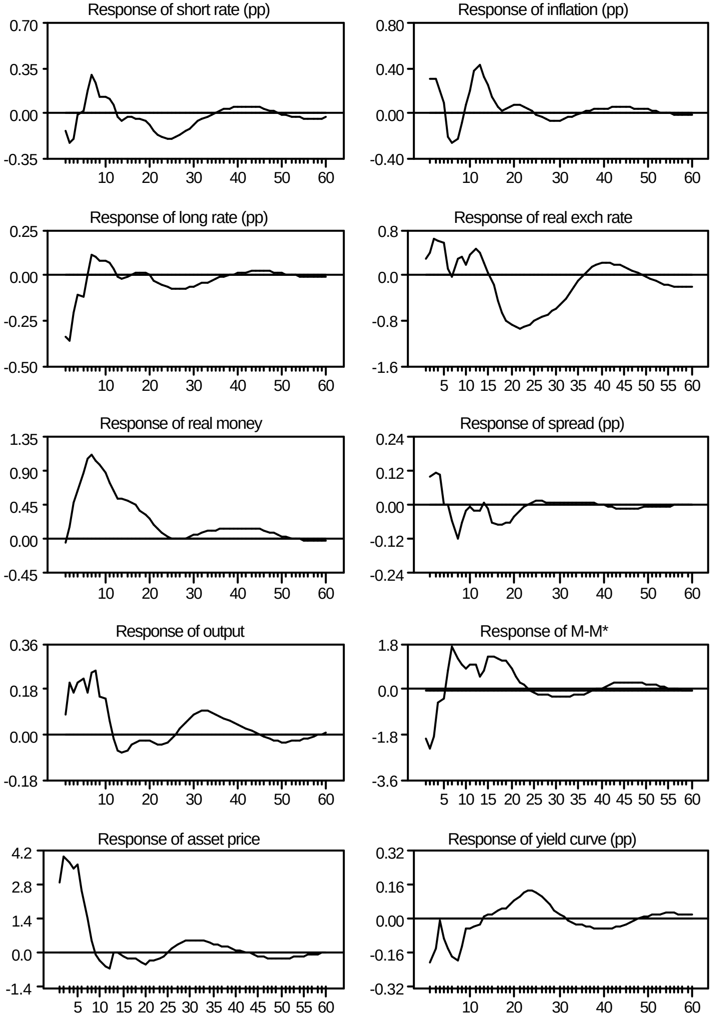
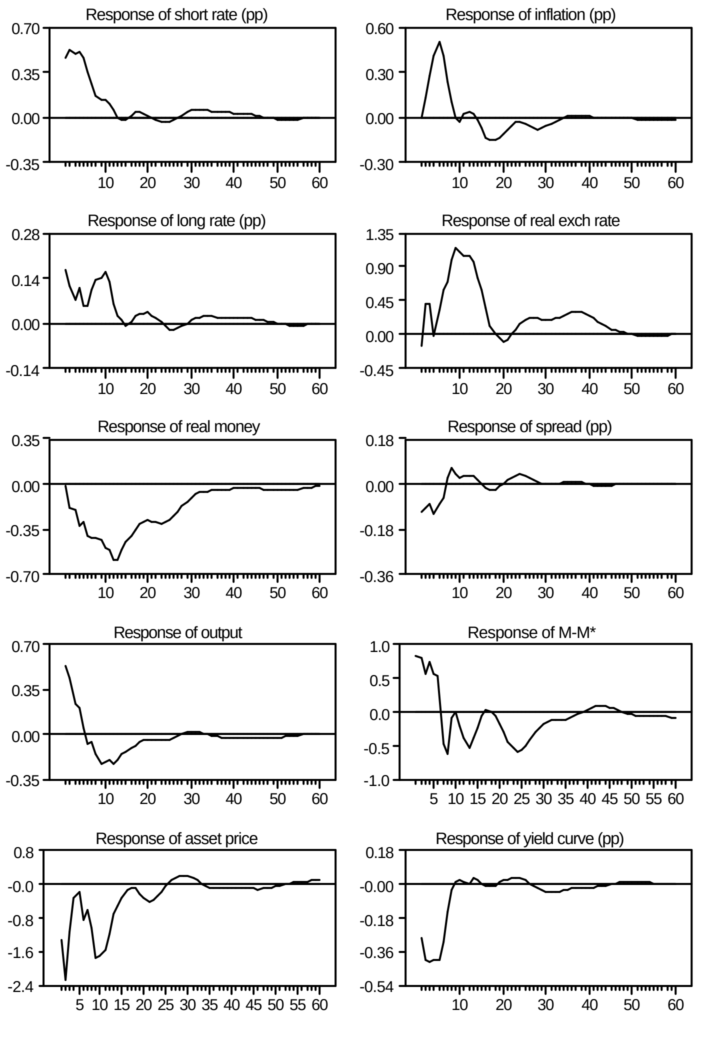


Chart 10: Aggregate demand shock impulse responses (% from base unless otherwise stated)



(d) Variance decomposition

An additional diagnostic on our identifying restrictions is the relative importance of the shocks in driving each of the variables in the system. To do this, we carry out a variance decomposition analysis of the system.

A variance decomposition analysis derives the contribution of each of the shocks to the variance of the forecast error for each variable at different time horizons. In other words, it shows how much of the variability of each of the variables is accounted for by each shock at different time horizons. In Table D below, we show a forecast error variance decomposition for each variable. The key points to note are:

(1) Movements in real M4 seem to be dominated at long horizons by financial intermediation, AS and nominal shocks. But at short horizons, temporary policy shocks appear to be quite important, suggesting that unexpected cuts in rates may have significant effects on money growth.

(2) As in a lot of other SVAR work, movements in output are dominated by AS shocks at long horizons. But at short horizons, AD shocks account for a large proportion of output movements. Nominal shocks do appear to have a significant effect on output, suggesting that there may be substantial costs of moving to a lower steady-state rate of inflation. Temporary policy shocks account for a small proportion (around 3%) of output variability at short horizons.

(3) Interest rates, though largely determined by nominal shocks in the long run, appear to be affected by most of the shocks to a fairly equal degree in the short run. The only exception is the temporary policy shocks, which only account for around 1% of the short-term variability in rates. This suggests that deviations from some average policy rule have been small. But it might also suggest that temporary policy shocks are being captured by one of the other temporary shocks.

(4) Around one quarter of the variability in deposit rates at long horizons is accounted for by financial intermediation shocks. And the term-premium shock has a large impact on long rates at short horizons. This supports our interpretation of the unrestricted shocks.

(5) More than half the variability in the real exchange rate at long horizons is due to foreign demand shocks, giving us some confidence in our identifying restrictions on this variable. By contrast, AD shocks, as we have identified them, appear to have little effect, even in the short run. This contrasts with other studies that have attempted a SVAR decomposition of the exchange rate (eg Astley and Garratt (1998)), which usually find IS or demand shocks to have an important role in explaining exchange rate movements. But the important point to stress here is that the restrictions we place on the relative foreign demand shock are very similar to those typically used to identify AD shocks, as we discussed earlier. In effect, we have split general demand shocks into two subsets: a temporary domestic demand shock and a permanent relative foreign demand shock. The latter appears to be more important in explaining exchange rate movements.

(6) Although inflation is dominated in the long run by the permanent policy shock, financial liberalisation shocks seem to have an implausibly large role in determining short to medium-term movements in inflation. This suggests that further over-identifying restrictions may be necessary to recover this shock fully.

Table D: Variance decomposition

is								
Horizon	**AS shock**	**Fin shock**	**Nom shock**	**For shock**	**Tpol shock**	**FRP shock**	**Term shock**	**AD shock**
1	0.24	0.11	0.05	0.13	0.01	0.10	0.04	0.31
2	0.25	0.13	0.03	0.15	0.02	0.06	0.06	0.31
4	0.21	0.13	0.02	0.19	0.01	0.04	0.04	0.35
8	0.18	0.14	0.02	0.18	0.01	0.05	0.08	0.34
20	0.16	0.17	0.22	0.11	0.02	0.05	0.06	0.21
100	0.02	0.38	0.53	0.01	0.00	0.01	0.01	0.03

il								
Horizon	**AS shock**	**Fin shock**	**Nom shock**	**For shock**	**Tpol shock**	**FRP shock**	**Term shock**	**AD shock**
1	0.12	0.22	0.06	0.09	0.03	0.00	0.38	0.09
2	0.13	0.29	0.09	0.05	0.02	0.00	0.36	0.06
4	0.14	0.33	0.14	0.06	0.02	0.00	0.26	0.05
8	0.10	0.35	0.23	0.07	0.02	0.01	0.17	0.05
20	0.04	0.37	0.47	0.02	0.01	0.01	0.06	0.02
100	0.01	0.40	0.58	0.00	0.00	0.00	0.01	0.00

m-p								
Horizon	**AS shock**	**Fin shock**	**Nom shock**	**For shock**	**Tpol shock**	**FRP shock**	**Term shock**	**AD shock**
1	0.02	0.43	0.12	0.08	0.34	0.01	0.00	0.00
2	0.03	0.48	0.09	0.08	0.29	0.01	0.01	0.01
4	0.08	0.49	0.07	0.06	0.20	0.01	0.07	0.02
8	0.17	0.43	0.06	0.04	0.13	0.01	0.14	0.02
20	0.29	0.52	0.03	0.02	0.04	0.01	0.06	0.02
100	0.16	0.56	0.24	0.03	0.00	0.00	0.01	0.00

y								
Horizon	**AS shock**	**Fin shock**	**Nom shock**	**For shock**	**Tpol shock**	**FRP shock**	**Term shock**	**AD shock**
1	0.27	0.04	0.14	0.03	0.00	0.00	0.01	0.51
2	0.24	0.03	0.15	0.03	0.03	0.00	0.05	0.48
4	0.39	0.04	0.17	0.02	0.03	0.00	0.06	0.29
8	0.53	0.09	0.18	0.01	0.02	0.01	0.06	0.10
20	0.64	0.11	0.14	0.02	0.01	0.01	0.02	0.05
100	0.68	0.26	0.04	0.00	0.00	0.00	0.01	0.01

Table D (continued)

pk								
Horizon	**AS shock**	**Fin shock**	**Nom shock**	**For shock**	**Tpol shock**	**FRP shock**	**Term shock**	**AD shock**
1	0.38	0.01	0.13	0.14	0.04	0.06	0.21	0.04
2	0.36	0.01	0.09	0.21	0.04	0.02	0.21	0.06
4	0.41	0.02	0.10	0.20	0.03	0.01	0.20	0.03
8	0.43	0.05	0.17	0.15	0.02	0.01	0.16	0.02
20	0.25	0.10	0.47	0.11	0.01	0.01	0.05	0.01
100	0.10	0.15	0.64	0.09	0.00	0.00	0.01	0.00

p								
Horizon	**AS shock**	**Fin shock**	**Nom shock**	**For shock**	**Tpol shock**	**FRP shock**	**Term shock**	**AD shock**
1	0.13	0.51	0.06	0.01	0.00	0.00	0.28	0.00
2	0.09	0.58	0.05	0.01	0.00	0.04	0.19	0.03
4	0.12	0.50	0.06	0.01	0.02	0.04	0.16	0.08
8	0.17	0.45	0.14	0.02	0.03	0.03	0.12	0.06
20	0.08	0.35	0.39	0.01	0.02	0.02	0.08	0.03
100	0.03	0.38	0.52	0.01	0.01	0.01	0.03	0.01

e								
Horizon	**AS shock**	**Fin shock**	**Nom shock**	**For shock**	**Tpol shock**	**FRP shock**	**Term shock**	**AD shock**
1	0.08	0.01	0.22	0.29	0.07	0.30	0.03	0.00
2	0.07	0.01	0.33	0.28	0.05	0.23	0.03	0.01
4	0.08	0.04	0.35	0.30	0.03	0.15	0.04	0.01
8	0.09	0.05	0.35	0.36	0.01	0.08	0.02	0.02
20	0.04	0.06	0.35	0.44	0.02	0.03	0.02	0.03
100	0.03	0.33	0.09	0.52	0.01	0.01	0.01	0.01

id								
Horizon	**AS shock**	**Fin shock**	**Nom shock**	**For shock**	**Tpol shock**	**FRP shock**	**Term shock**	**AD shock**
1	0.18	0.00	0.00	0.31	0.12	0.00	0.01	0.38
2	0.22	0.04	0.00	0.28	0.08	0.00	0.02	0.37
4	0.21	0.05	0.00	0.27	0.05	0.01	0.01	0.41
8	0.17	0.03	0.01	0.27	0.03	0.02	0.05	0.42
20	0.18	0.03	0.19	0.17	0.05	0.04	0.06	0.28
100	0.02	0.23	0.68	0.02	0.01	0.00	0.01	0.03

4 Practical uses of the model

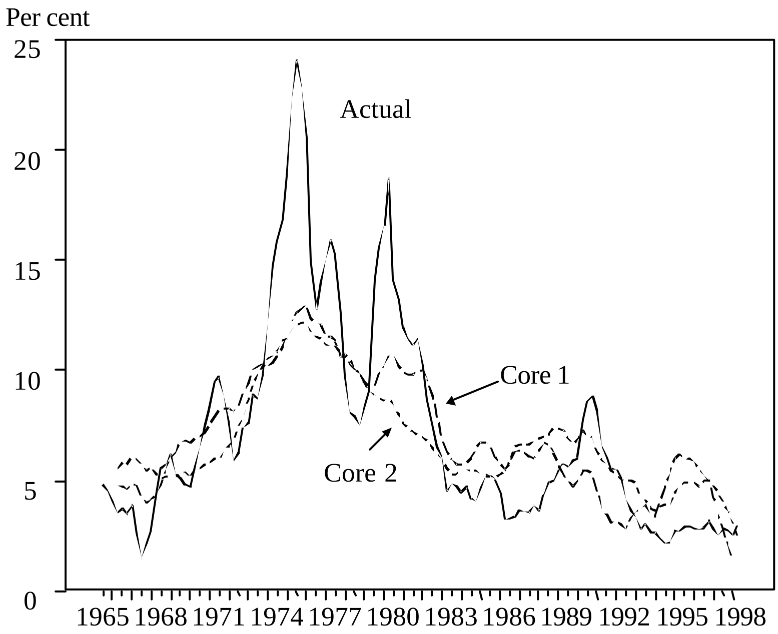
(a) Generating output gaps and liquidity overhangs

One obvious use of the model is to generate trend levels for each of the variables, using the common stochastic trends we have identified. At first glance this seems straightforward. We simply use the long-run impact matrix of the shocks, *F*, to generate a trend for each variable that is a linear combination of the stochastic trends that drive that variable in the long run.

But we must be careful here, as use of the word ‘trend’ means different things in different contexts. In particular, there may be circumstances when the trend we wish to construct would include the cyclical effects of some of the permanent shocks. A good example is the output gap. The concept of the ‘trend’ level of output used to construct an output gap is typically some notion of the supply capacity of the economy. In this case, we would want to include the cyclical effects of productivity shocks on output, since these clearly affect the supply capacity of the economy at a given moment in time. To put this another way, we would want our output gap to reflect shocks that only have a temporary effect on output, such as aggregate demand and monetary policy shocks.

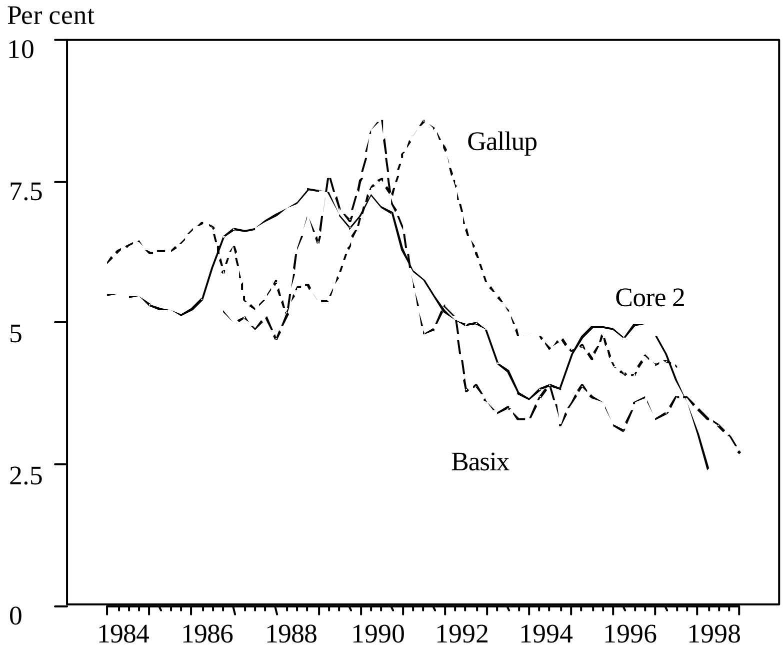
Another good example is that of estimating the trend in inflation or ‘core’ inflation. Do we want to include the ‘cyclical’ or dynamic effects of the nominal stochastic trend? One way to answer this question is to say ‘no’ if we are after a measure of the underlying inflation or nominal target of the authorities; but ‘yes’ if we are after a measure of inflation expectations that would enter an expectations-augmented Phillip’s curve, for example. The dynamic effects of a change in the nominal trend/inflation target could be interpreted as the adjustment of inflation expectations as the private sector learns about a new regime. Chart 11 below shows these two different measures of core inflation. Core 2, which includes the cyclical effects of the nominal shock, shows less variation than Core 1, which excludes these effects. This could be interpreted as partial adjustment of inflation expectations to changes in the underlying target.

Chart 11: Core inflation



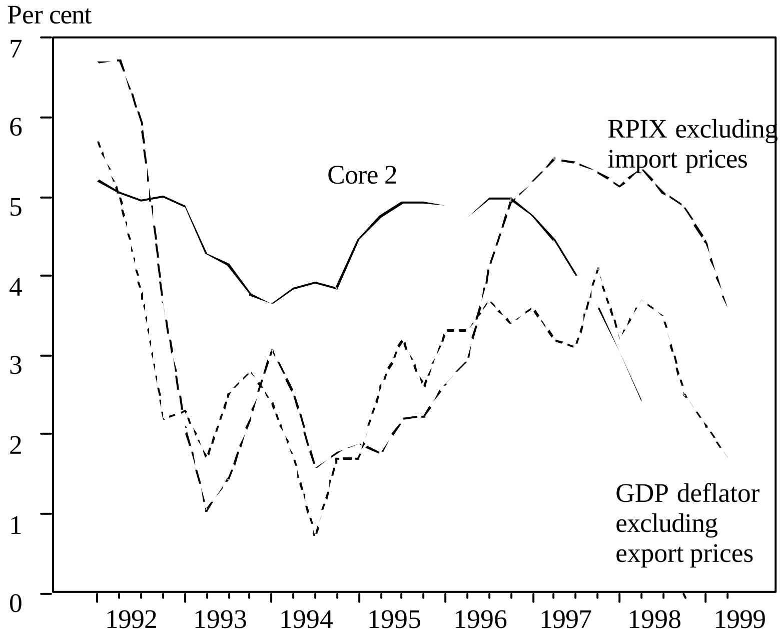
Charts 12 and 13 below compare the Core 2 measure of inflation with other measures of underlying inflation. Chart 13 shows a comparison with two survey-based measures of inflation, the Gallup index (discontinued from 1997 Q3) and the Basix trade union survey. There is a reasonable correlation between our estimate of core inflation and both survey-based measures.

Chart 12: Core inflation and survey-based measures of inflation expectations



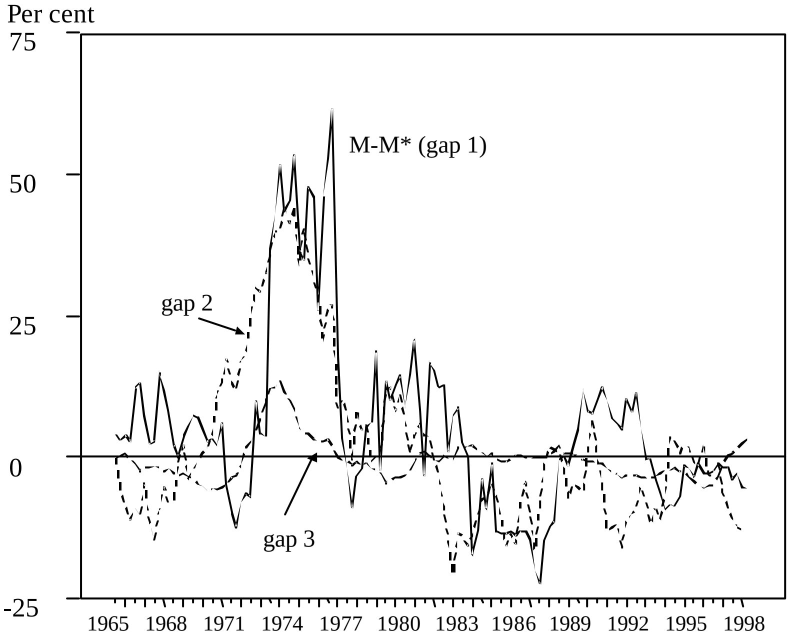
A more interesting relationship is apparent in Chart 13, where Core 2 is plotted next to recent measures of domestically generated inflation (DGI), which attempt to strip out international influences on UK prices. Changes in the Core 2 estimate of underlying inflation appear to have led recent movements in DGI inflation on both definitions.

Chart 13: Core inflation and DGI measures of inflation



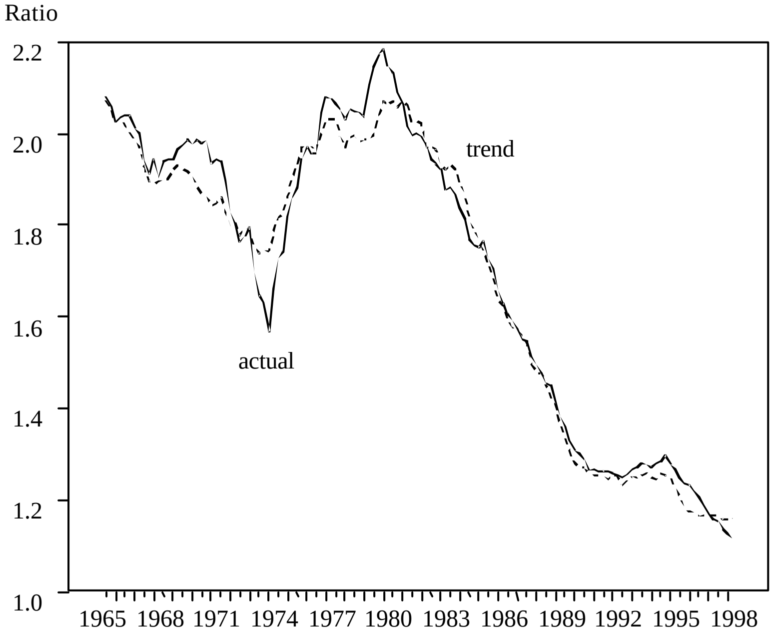
The issue of the appropriate trend measure becomes even more complicated when measuring the liquidity gap or monetary overhang. Previous work has used the estimated long-run relationships from cointegration analysis to generate liquidity gaps, which were discussed in Section 3. But this measures equilibrium money holdings when the determinants of the long-run demand for money are at their *actual* levels. If we were to take the trend in money holdings implied by the long-run effects of the permanent shocks, we would (in effect) be measuring equilibrium money holdings when the determinants of the long-run demand for money were themselves at their trend level. Including the cyclical effects of some of the permanent shocks (such as the financial intermediation shock or productivity shock) gives different estimates depending on which shocks' cyclical effects are included. So estimates of the liquidity gap will depend critically on what is included in the definition of the long-run demand for money. If we consider that permanent rather than actual income should be in the long-run money demand function, we should go for a trend that excludes the cyclical effects of the productivity shock. Below we show three different estimates of the liquidity gap: the first (gap 1) is the cointegrating vector (M-M*) estimated in Section 3; the second (gap 2) is the trend excluding the cyclical effects of the permanent shocks driving money; and the third (gap 3) is the trend including the cyclical effect of the permanent shocks. All three show quite different patterns. In particular, the third gap is a lot less volatile than the first two. This suggests that the definition of equilibrium money holdings matters a great deal for determining the extent of a liquidity overhang.

Chart 14: The liquidity gap



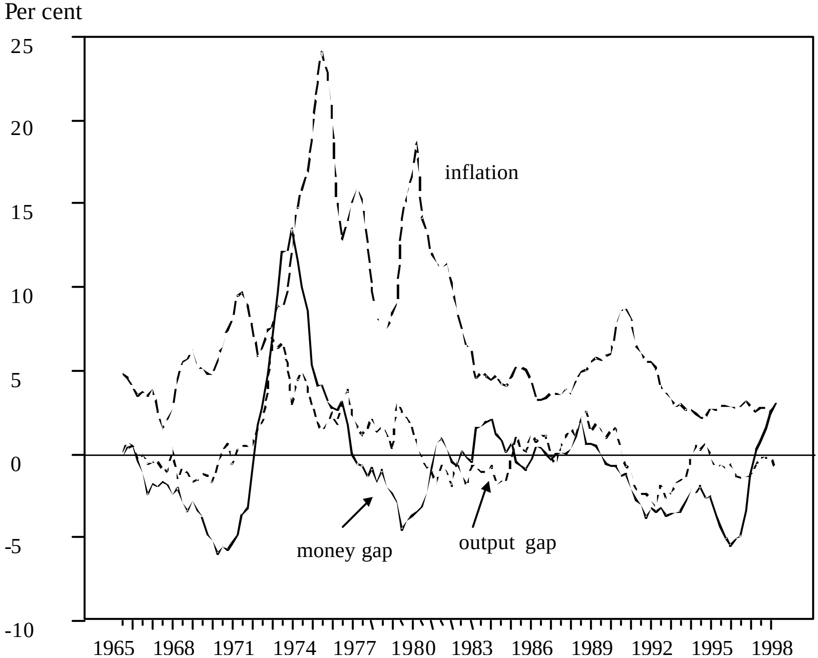
Any estimate of trend money holdings can of course be transformed into a trend for velocity. Chart 15 below shows the trend for velocity where the cyclical effects of the permanent shocks are included.

Chart 15: Trend M4 velocity



Combining our estimates of the output and liquidity gaps, we show below a chart that shows their relationship with the annual rate of inflation. The liquidity gap (using the less volatile measure in Chart 14) and the output gap appear, if anything, to be fairly coincident. And both appear to have some lead over inflation in the recent past. But of course, we should not necessarily expect to see any particular systematic leading or lagging-indicator properties between these gaps and inflation, since the impulse responses indicated that these vary with the type of shock.

Chart 16: Gaps compared



(b) Historical decompositions

Another use of the model is that we can also look at a historical decomposition of the variables in the system. This differs from the variance decomposition, as it attempts to measure the relative importance of the shocks over particular historical episodes rather than their average importance over the sample period. A historical decomposition of the system is one of the useful outputs the empirical model has to offer the forecasting process, in that it helps to indicate the sources of the most recent movements in demand, output and inflation.

We look at two major historical episodes: the appreciation of sterling during the period 1979 to 1981; and the period of high output growth during the late 1980s. But the approach could obviously be used to analyse a variety of case studies.

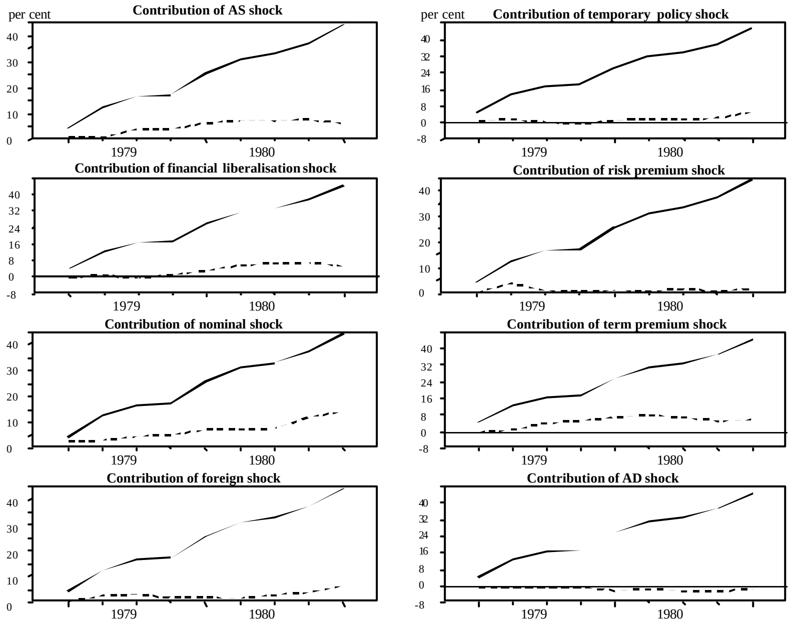
The appreciation of sterling 1979-81— oil or monetary policy ?

Between 1979 Q2 and 1981 Q1 the real value of sterling in terms of relative unit labour costs rose by almost 40%. At the time there was considerable debate over whether this rise in the real exchange rate was driven by: (i) the impact of higher oil prices on the trade balance, since the United Kingdom had become a net exporter of oil by the late 1970s; or (ii) the restrictive monetary policy implemented by the incoming Conservative government designed to lower the underlying rate of inflation. Buiter and Miller (1981) showed that both shocks might cause an overshooting of the real exchange rate in the short run and, in the case of oil, a permanent rise in the equilibrium real exchange rate in the long run.

In terms of the VAR we can attempt to shed light on this issue by analysing the contributions of the various structural shocks to exchange rate movements over this period. A strong contribution from the aggregate supply shock or possibly the relative foreign demand shock would suggest the oil price was more responsible for the rise in the real exchange rate. A strong contribution from the permanent nominal shock, on the other hand, would suggest that restrictive monetary policy was the chief driving force.

Chart 17 below shows the cumulative rise in the real exchange rate between 1979 Q2 and 1981 Q1 relative to the cumulative contribution of each of the structural shocks. The decomposition suggests that around a third of the rise might be explained by the permanent monetary policy shock, while at most another third could be attributable to oil through the aggregate supply and relative foreign demand shocks.

Chart 17: The rise in sterling 1979-81



Explaining the output gap in the late 1980s

Charts 16 showed that a significant output gap is estimated to have emerged during the late 1980s. In annual terms real output grew by around 3.5% on average between 1984 Q4 and 1990 Q2. And this presaged a pick-up in inflation to around 9% by the middle of 1990. Several factors have been suggested to account for the emergence of this output gap:

(i) The income tax cuts in the 1987 and 1988 budgets and their impact on consumption. This would suggest that demand shocks were the chief underlying cause of the output gap.

(ii) The deregulation of credit markets. The process of financial liberalisation in the late 1980s made it easier for the household sector to obtain credit, especially through borrowing secured on property. And this rather than tax cuts fuelled the pick-up in demand growth. This would suggest that financial liberalisation shocks had a significant effect on demand and output.

(iii) Shadowing the Deutsche Mark. Over this period the Chancellor attempted, either formally or informally, to keep sterling tied to the Deutsche Mark. Even though it was argued that this would lock the United Kingdom into Germany's low inflation rate, the upward pressure on sterling at the time may have forced the authorities to lead too loose a monetary policy, with the implication that the underlying rate of nominal expansion or implicit inflation target may have risen. For example there may have been a rise in the equilibrium real exchange rate which put upward pressure on sterling. And in response the authorities held interest rates at relatively low levels to prevent the nominal exchange rate from rising. The resulting fall in real interest rates and build-up of a liquidity overhang would then explain the expansion of aggregate demand and the emergence of an output gap. This argument would suggest that the output gap was driven primarily by permanent monetary policy shocks, possibly with a contribution from relative foreign demand shocks which pushed up the equilibrium real exchange rate.

Chart 18 below shows the cumulative rise in the output gap (which we measure here as the cumulative rise in output excluding the cumulative impact of aggregate supply or productivity shocks) relative to the contribution of each of the shocks from 1984 Q4 to 1990 Q2.

- Aggregate demand shocks appear to have some role in sustaining the output gap during 1988 but their cumulative effect diminishes in 1989 and 1990. So on this evidence tax cuts would appear to have had a small transitory role in boosting demand and output.

- Financial liberalisation shocks have a small but more persistent effect on the output gap, suggesting at least some impact of financial deregulation on demand. An examination of the historical decomposition of real money balances over this period shows a much stronger contribution from financial liberalisation, suggesting a strong shift in trend velocity.

- Permanent nominal shocks seem to have made the most important contribution to the output gap, at least to the height of the boom in 1988 after which it dies away somewhat as policy began to get tightened from late 1988 onwards. This positive contribution was supported by the relative foreign demand shock, which appears to have raised demand and the equilibrium real exchange rate particularly over the period 1987-88, when the authorities were most active in keeping a lid on the exchange rate. This suggests that monetary policy was working hard to prevent the exchange rate from rising in response to a shift in its equilibrium value. This is supported by Chart 19 which shows the persistent negative contribution of the permanent monetary policy shock to the real exchange rate over this period.

Chart 18: Explaining the output gap in the late 1980s

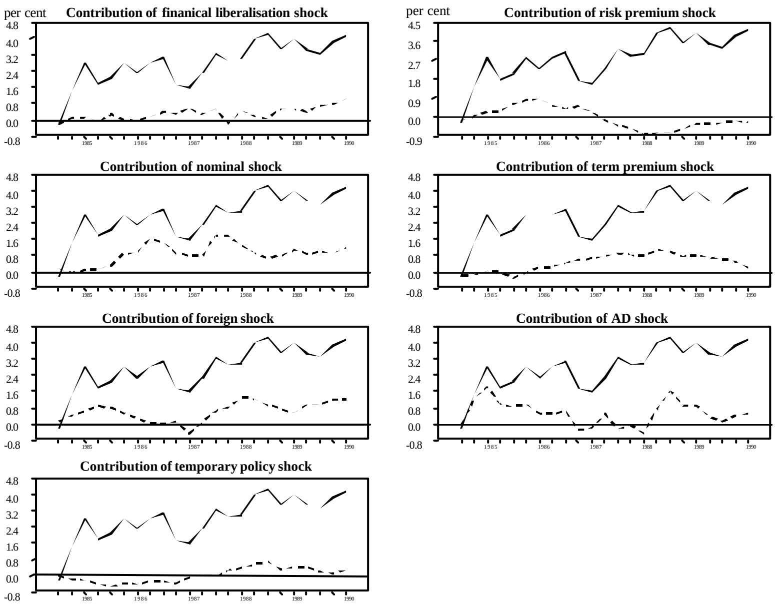
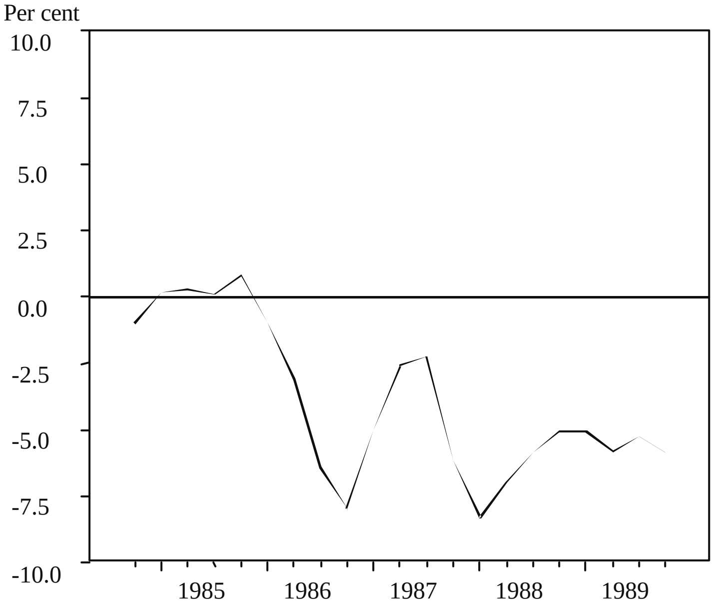


Chart 19: Contribution of permanent policy shock to the real exchange rate



So overall the model would support (iii) as the major explanation of the emergence of a positive output gap in the late 1980s.

(c) Conditional forecasts

Another way the model can be used is to carry out conditional forecasts based on a small number of assumptions about the future path of the underlying stochastic trends. In particular, we can make forecasts under different assumptions about trends in inflation expectations, financial liberalisation and productivity growth.

Forecasts can also be made conditional on particular paths for monetary policy, which may be different from the path generated by the model, or from the path expected by agents. For example, the MPC currently forecasts inflation conditional on a constant short-term nominal interest rate, which is typically different from the path implied by interest rate futures or bond yields. In the context of our model, conditioning on a path for the interest rate that differed from the path predicted by the model would imply a series of monetary policy surprises over the forecast period, ie we would forecast conditional on a path for the monetary policy shocks. The important issue here is one of signal extraction. In the light of interest rates turning out differently from expected, how much do agents assume that this is a temporary policy shock and how much a permanent shift in the nominal target of the authorities? We intend to examine some of these issues in future work.

5 Conclusions

We have estimated a small structural model, involving eight variables that theory predicts play an important role in the monetary policy transmission mechanism. We found that we were able to decompose movements in these variables into four permanent and four temporary shocks, each of which was identified according to economic criteria. The properties of the model seem broadly sensible, and there do not seem to be any ‘price puzzle’ problems with the response of inflation to either permanent or temporary monetary policy shocks. But there are some features of the model (eg the impact of the financial liberalisation shocks on inflation) that we intend to look at further in future work. The model also builds on previous work in the Bank, by showing explicitly how different shocks produce a different interaction between money holdings, monetary overhangs, activity and prices.

We have also shown some of the practical uses of such a model. The model can be used to produce estimates of the output gap, liquidity gap, and core inflation. It can also be used to identify which shocks have been the most important in driving each of the variables over a given time period. Perhaps more importantly, the model can also be used to provide conditional forecasts, based on different assumptions about the future paths of the stochastic trends and temporary shocks.

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