Money, Prices and Liquidity Effects: Separating Demand from Supply*

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Abstract

In the canonical monetary policy model, money is endogenous to the optimal path for interest rates, output. But when liquidity provision by banks dominates the demand for transactions money from the real economy, money is likely to contain information for future output and inflation because of its impact on financial spreads. And so we decompose broad money into primitive demand and supply shocks. We find that supply shocks have dominated the time series in both the UK and the US in the short to medium term. We further consider to what extent the supply of broad money is related to policy or to liquidity effects from financial intermediation.

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1 Introduction

The proposition that inflation is a monetary phenomenon often sits uncomfortably with the perhaps mixed evidence that money has significant information for inflation at the policy horizon.[1] A standard response to this puzzle is that the path of real output and inflation (nominal output) over the business cycle will generate a proportional demand for money balances, which will be supplied elastically by the central bank at an interest rate appropriate for the maintenance of nominal stability and that broad money will be multiplied out by the act of financial intermediation. In the long run output will be determined by real factors leaving the supply of money to pin down the price level.[2] In this paper we take this dichotomy between the short and long run correlation between money and prices and explore the impact of decomposing broad money innovations into those that reflect demand and supply separately. We can also consider to what extent the broad money supply is not pinned down by the policy function, which acts on policy rates alone. We consider whether financial intermediaries may separately impact on the supply of money and so generate excesses or shortages in nominal demand which impact directly on inflation.

In this paper, we build upon the recent work of Goodhart (1999), King (2002) and Chadha *et al.* (2008) who suggest that liquidity effects may impact on monetary conditions independently of the policy function. Specifically in a model (see, Goodfriend and McCallum, 2007) where banks supply loans as a function of the marginal costs of loans provision, the external finance premium faced by borrowers is proportional to these costs

[1] The breakdown of the medium link between money and nominal expenditure has been well documented and played a key role in the move away from monetary targetry. See Goodhart (1999).

[2] See Lucas (1996) for a simple exposition of this point.

and to the value of collateral or monitoring. Financial spreads are thus driven down by any increases in the marginal efficiency of loans production and by the resulting liquidity in the money markets, which may lead to excessive levels of output in the economy. But when banks supply deposits simply to meet productive capacity, liquidity is not exogenously reflected in excessive demand. And so we find that when financial sector productivity is a dominant source of business cycle fluctuations some attention needs to be paid to the nexus of financial spreads and liquidity. Specifically when spreads fall (increase) and liquidity rises (falls), the monetary policy maker might have to pay particular attention to offset these expansionary (contractionary) impulses.[3]

There is a large literature on the relationship between money, prices and output.[4] To some extent the debate has been brought back into sharp relief by the recent and ongoing disturbances in money markets, which have may have disrupted the link between monetary policy and broad liquidity provision. And we are interested here in using the sign restrictions suggested above to identify separately demand and supply shocks in the broad money markets. Originating with Faust (1998), Uhilg (2001) and Canova (2002) VARs can be estimated with Bayesian priors on the sign response to demand or supply shocks in the money markets. Specifically, we run VARs in broad money and measures of the external finance premium to identify primitive demand and supply shocks to the broad money market where supply shocks (a so-called liquidity effect) cause spreads and money to move in the opposite directions

[3]Despite the mythology about modern macroeconomics and money, the kind of disconnect between money markets and monetary policy was considered in work by Carlstrom and Fuerst (1995) and by Ireland (1996), the latter of whom found that in the presence of significant changes in the required proportion of money balances to transactions, interest rates may not operate as a good instrument of monetary policy.

[4]See Christiano *et al.* (1999) for a comprehensive overview of the literature.

and demand shocks lead to spreads and money to move together.

As earlier influential work by Bernanke and Mihov (1998), we find strong evidence for a liquidity effect that can be shown to dominate monetary behaviour in both recent UK and US data. And as Lastrapes and McMillin (2004) we find significant effects from financial prices on supply factors for broad money. More work is required to decompose further the equilibrium outcomes we observe on monetary aggregates, particularly in sectoral money aggregates, but tentatively we suggest that policy, particularly in the US, may not have acted to fully offset the exogenous compression of market interest rates by financial markets. Given recent developments in financial markets, that have started to de-leverage after a long period of balance sheet expansion, these results may provide a useful diagnostic on the extent to which policy may have been inattentive.[5]

This paper is structured as follows. In section 2, we outline a simple monetary model in which the exogenous supply of liquidity perturbates output and inflation. In section 3 we outline our methodology for identifying a series of VARs in money and interest rates. In section 4 we outline our basic results and provide some analysis of or findings and we finish with some concluding remarks.

[5] See the discussion by the IMF (2008) on the implications of leverage and deleveraging in financial markets. The Bank of England, Berry *et al* (2007), is clear on the need to monitor monetary data on the outlook for inflation and on the information that may be contained in price and quantity data.

2 A Liquidity Effects Model: Money and External Finance Premia

In this section we develop a simple endowment economy model of a representative infinitely lived household.[6] The model is used to show how policy needs to account for financial disturbances, as represented by unanticipated changes in the ability of money to finance consumption. And also how money is ultimately related to changes in the external finance premium, which reflects both the nominal interest rate and a rate reflecting this liquidity provision. We sketch a simple version of this model as a quadrant diagram and relate our estimation strategy to one of the quadrants, as a reduced form of this model.

A simple model might think of a household receiving a stochastic endowment that cannot be stored, which is exogenous and it is received at the end of the period. The household thus has to decide over two stores of wealth, real money balances, $\frac{M_t}{P_t}$, and a one-period nominal bond, B_t. The nominal bond purchased at date t pays one unit of currency at date $t+1$ and has a price of $q_t \left(= \frac{1}{1+i_t}\right)$.

The household maximizes utility over an infinite horizon as is standard. The cash-in-advance economy is structured as follows. At the end of previous period a stochastic shock to liquidity alters the value of money, $\upsilon_{t-1} M_{t-1}$, which changes the required money balance to effect consumption decisions and results from financial intermediation; in addition, a real endowment shock, y_t, is realised at the start of the next period. Following the money transfer, returns from maturing bonds and receipt of endowment, the representative household decides on how to allocate its wealth between money balances and nominal discount bonds.

[6] See Lucas (1982) and Labadie (1994).

Once the asset market has closed, the household uses its money balances acquired at the beginning of the period M_t to finance its consumption purchases, $c_t p_t$, where p_t is the price level at date t. The household then receives its nominal endowment income $p_t y_t$, which it cannot spend until the subsequent period.

The representative household maximises the following utility problem:

$$\max U = E_t \sum_{i=t}^{\infty} \beta^{i-t} u\left(c_i\right), \tag{1}$$

where β is the subjective rate of time preference, E_t, are expectations formed at time and $u\left(c_i\right)$ is a mapping from consumption this period to utility in the same period. Subject to the household budget constraint:

$$\frac{p_{t-1}}{p_t} c_{t-1} + \frac{q_t}{p_t} b_t + \frac{M_t}{P_t} = \frac{p_{t-1}}{p_t} y_{t-1} + \frac{b_{t-1}}{p_t} + v_{t-1} \frac{M_{t-1}}{P_t}, \tag{2}$$

and the cash-in-advance constraint:

$$c_t \leq \frac{M_t}{P_t} v_t. \tag{3}$$

The lagrange multiplier attached to the first constraint is $\lambda_{1,t}$ and to the second is $\lambda_{2,t}$. The first order conditions of this problem with respect to c_t, b_t and $\frac{M_t}{p_t}$ are given respectively by:

$$u'\left(c_t\right) = \lambda_{2,t} + E_t \beta \lambda_{1,t+1} \frac{p_t}{p_{t+1}}, \tag{4}$$

$$\lambda_{1,t} \frac{q_t}{p_t} = E_t \lambda_{1,t+1} \frac{\beta}{p_{t+1}}, \tag{5}$$

$$\frac{\lambda_{1,t}}{v_t} = \lambda_{2,t} + E_t \beta \lambda_{1,t+1} \frac{p_t}{p_{t+1}}. \tag{6}$$

By equating (6) to (4) we find that:

$$\lambda_{1,t} = u'(c_t)\, v_t$$

And so the equilibrium condition for nominal bonds is:

$$E_t \frac{u'(c_t)}{\beta u'(c_{t+1})} = E_t \frac{v_{t+1}}{v_t} \frac{p_t}{p_{t+1}} (1 + i_t), \tag{7}$$

which says that the household consumption path will equate the present value of consumption in successive periods subject to deviations in the nominal interest rate, inflation and financial liquidity.[7] Following Woodford (2003)[8] the appropriate Wicksellian policy will take the following form:

$$z_t \equiv E_t \frac{u'(c_t)}{\beta u'(c_{t+1})}, \tag{8}$$

where z_t is the intertemporal marginal rate of substitution in consumption. And so the interest rate policy rule can be written as follows:

$$1 + i_t = \phi(p_t, v_t, z_t), \tag{9}$$

which means that an equilibrium condition will require:

$$E_t \frac{p_{t+1}}{v_{t+1}} z_t = \frac{p_t}{v_t} \phi(p_t, v_t, z_t), \tag{10}$$

which means that the policy maker has to consider a stable path for financial shocks as well as the price level to ensure a stationary equilibrium. We now turn to the implications for growth, inflation and spreads in this model. Adopting log utility, $u(c_t) = \ln c_t$, we can re-write (8) as:

$$E_t \frac{c_{t+1}}{c_t} = E_t \frac{v_{t+1}}{v_t} \frac{p_t}{p_{t+1}} \beta (1 + i_t), \tag{11}$$

[7] This point was made by Ireland (1996).

[8] See Walsh (2003) for an exposition of this point.

which we can log-linearise to obtain:

$$E_t \triangle c_{t+1} = i_t - E_t \pi_{t+1} + E_t \triangle v_{t+1}, \tag{12}$$

which is now a familiar intertemporal spending equation and tells us that consumption growth is tilted by liquidity effects on broad money as well as the interest rate. If we think in terms of a short run inflation induced by spending, we can iterate this expression forward to obtain:

$$c_t = -E_t \sum_{j=0}^{\infty} \left(i_{t+j} - \pi_{t+j+1} + \triangle v_{t+j+1} \right), \tag{13}$$

which can be substituted into a New Keynesian Phillips curve to obtain:

$$\pi_t = -E_t \kappa \sum_{j=0}^{\infty} \beta^j \left(i_{t+j} - \pi_{t+j+1} + \triangle v_{t+j+1} \right), \tag{14}$$

where κ is the slope of the Phillips curve. And tells us that inflation and consumption will be tilted by the liquidity premium as well as the policy rate adjusted for expected inflation. As expected money growth from the cash in advance constraint is:

$$E_t \triangle c_{t+1} = E_t \triangle m_{t+1} - E_t \pi_{t+1} + E_t \triangle v_{t+1} \tag{15}$$

$$E_t \triangle m_{t+1} = i_t$$

which tells us that in the long run higher money growth will simply drive up the nominal rate. So in the short run the policy rate and the liquidity premium will determine the deviation of consumption from its long run level and so the rate of inflation, but in the long run we might expect, with stable real rates, inflation and liquidity shocks, money growth to feed simply into the inflation component of nominal interest rates.

We can sketch this model in a four quadrant space to illustrate our basic points more fully. The north-east quadrant of Figure 1 shows the equilibrium in the market for central bank money, M_0, with demand, M_0^d, negatively sloped and the supply of central bank money, M_0^s, perfectly elastic with respect to the chosen policy rate, i_t. Shocks to demand for central bank money thus neither impact on policy rate nor on the level of aggregate demand in the economy. The market clearing quantity of central bank money is multiplied by MM in the south-east quadrant to arrive at a level of broad money, M_B, where we can think of this level of broad money as the outcome of a process of financial intermediation. The steeper is the MM curve the higher is the money multiplier. The south-west quadrant clears the broad money market in supply, which increases in the spread charged over the policy rate, efp_t, and demand for broad money, which from the cash in advance constraint is a function of consumption, c_t, which is itself determined by the spread. At the steady-state level of market rate interest rates, consumption, c_t, will equal its long run level, $\bar{c}$. But if the spread is above (below) the long run level consumption will be below (above) $\bar{c}$ and inflation will be below (above) any target. In this sense, higher (lower) spreads will be associated with lower (higher) inflation and consumption as in (13) and (14).

To re-iterate in the north-west quadrant inflation, π_t, results from any deviation in consumption from its long run level and we can sketch the implication from an exogenous shift in broad money supply in the south-west quadrant. A shift out (in) in the broad money supply schedule[9] will lead to a reduction (increase) in the efp and consequently to an increase (decrease) in consumption and so inflation. Equally, a shock to the demand for broad money, will show up as having the same sign on the efp and the

[9] We hold aside the policy response or any implied money multiplier shift to aid pictoral clarity.

quantity of broad money or liquidity. And so we can identify shocks to the market for broad money, with the help of market interest rates to uncover demand or supply perturbations to this market and then assess the extent to which one type of shock or other is related to inflation and aggregate price level dynamics. This is the purpose of the next section.

3 Identifying Demand and Supply in the Money Market

In this section we describe how to identify money and supply shocks using sign restrictions with a Bayesian VAR on the model variables described in the south-west quadrant of Figure 1 in section 2. We follow Canova and De Nicoló (2002), Uhlig (2005) and Faust (1998) and adopt the standard reduced form VAR of order p:

$$Y_t = B(L)Y_{t-1} + u_t, \tag{16}$$

where $Y_t = (\Delta m_t, efp_t)$ is a 2×1 vector of data for the first difference of log-money, m_t, and the external finance premium, efp_t,[10] $B(L)$ is a polynomial of order p and L is the lag operator. Note in the estimation we use a stacked version of the VAR model: $Y_t = X_t B + u_t$, where X_t is a matrix of lagged model variables: Y_{t-n}, $n = 1...p$.

The main point of this exercise is to identify the structural shocks contained in the residual vector. Let $\varepsilon_{j,t}$ for $j = s, d$ denote money supply and money demand shock respectively. Canonical transformations of such shocks require them to be *i.i.d.* white noise processes having zero mean,

[10] As stressed in Canova and de Nicoló (2002) in order to interpret the responses to shocks as short-run dynamics around a steady-state, the VAR representation must be stationary. For this reason broad money has been first-differenced.

unitary variance and to be serially uncorrelated at all leads and lags. We can therefore denote the relationship between our structural shocks $\varepsilon_{j,t}$ and the vector of VAR residuals, $u_{j,t}$, as:

$$u_{j,t} = A\varepsilon_{j,t}, \tag{17}$$

where A is a 2×2 matrix. The main point is that by identifying A we can automatically recover the structural shocks $\varepsilon_{j,t}$. An equivalent formulation for (17) is:

$$\Sigma_t = E(u_{j,t}u_{j,t}^{'}) = AE(\varepsilon_{j,t}\varepsilon_{j,t}^{'})A', \tag{18}$$

where Σ_t is a symmetric variance-covariance matrix and A is our vehicle to identify the structural shocks.[11] To accomplish this we focus on the a^j column of A containing the j-th identifying restriction and we consider the corresponding impulse response function. Given the structural impulse vector, a^j, the set of all structural response coefficients of the bivariate system up to horizon h, denoted as $\phi_{1,\ldots,}\phi_h$, can be computed using the estimated coefficient matrix $B(L)$ from the reduced form VAR:

$$\begin{aligned} \phi_s^j &= \sum_{n=0}^{s} B_{s-n}\phi_n^j \qquad s \geqslant 1 \;\; B_{n-s} = 0 \;\; s - n \geqslant p \\ \phi_0^j &= a^j. \end{aligned} \tag{19}$$

Note that the impulse vector a^j maps the innovation to the j-th structural shock into the contemporaneous impulse responses of our variables, ϕ_0.

[11] As stressed by Canova and De Nicoló (2002) there is a multiplicity of orthogonal decompositions. For any orthogonal matrix Q, with $QQ^{'} = I$ also $\Sigma = AQQ^{'}A^{'}$ is an admissible decomposition for Σ. One example is the Cholesky decomposition of Σ, where A is lower triangular. However alternative orderings of the variables in the system implying different representations for Σ may produce different structural systems.

Informal restrictions are made on the cumulative impulse response function ϕ_h, so that we define $\bar{A}_h$ as the matrix of identifying restriction for time interval h, whose elements can fulfill any of the following inequality constraints $\bar{A}_{ij,h} > 0$ or $\bar{A}_{ij,h} < 0$. Let us (safely) assume that a positive money supply shock has a positive effect on money, Δm_t, and a negative effect on the financial spread, efp. In practice such shock represents an increase in liquidity provision originated either from monetary policy or from external shocks, hence: $\bar{A}^s = \left[\begin{smallmatrix} + \\ - \end{smallmatrix}\right]$. Similarly a positive money demand shock has a positive effect on money and a positive effect on the external finance premium, hence: $\bar{A}^d = \left[\begin{smallmatrix} + \\ + \end{smallmatrix}\right]$.

Therefore the matrix $\bar{A}$ of identifying restrictions takes the following form:

$$\bar{A} = \begin{bmatrix} + & + \\ - & + \end{bmatrix}. \tag{20}$$

We concentrate on the temporary impact of identified structural shocks by imposing sign restrictions for the first 6 months in the cumulative impulse response function defined through the coefficients $\phi_{h,\ h=1\ldots6}$.[12] Note that in our specification of a stationary VAR, the permanent impact from shocks on the growth rate of money or the external finance premium has been ruled out.

The full procedure to identify structural shocks using sign restrictions is implemented using a Bayesian VAR setting as in Uhlig (2005). We start from the MLE estimator of the reduced VAR(p) process (16) in stacked format: $Y_t = X_t B + u_t$, whose lag length is chosen using canonical information criteria such as AIC, Schwarz and Hannan-Quinn:

[12] We admit that the choice of six months is aribitrary and can easily implement restrictions over different horizons, we suggest that, as 2 quarters is generally thought to the start of the business cycle frequency, a response of a given sign of up to six months might be thought of as comparable to the limit in the length of a money market shock.

$$\widehat{B} = (X'X)^{-1} X'Y,\ \widehat{\Sigma} = \frac{1}{T}\left(Y - X\widehat{B}\right)'\left(Y - X\widehat{B}\right). \tag{21}$$

To fit the data with a Bayesian VAR model, we assume a standard diffuse prior on the VAR coefficients and on the covariance matrix.[13] We also assume a Gaussian process for the data, therefore the prior and posterior of (B, Σ) belong to the Normal-Wishart family. The Normal-Wishart distribution assumes that the uncertainty of (B, Σ) can be decomposed into the variation of B around a mean, $\overline{B}$, and of Σ around a positive definite mean covariance matrix, S. The mean coefficient matrix $\overline{B}$ is of size $ml \times m$ where m is the number of variables (in our model $m = 2$) and l is the optimal lag-length of the VAR while S is of size $m \times m$. The probability of the posterior distribution also depends on a positive definite matrix N of size $ml \times ml$ and a degrees of freedom real number $v \geqslant 0$ that describes the uncertainty of (B, Σ) around $\left(\overline{B}, S\right)$.

In the posterior Σ^{-1} follows a Normal-Wishart distribution $W\left(S^{-1}/v, v\right)$ and the column-wise vectorisation of B, $vec\,(B)$, follows a Normal distribution conditional on Σ: $N\left(vec\left(\overline{B}\right), \Sigma \otimes N^{-1}\right)$ where $\otimes$ is the Kronecker product. We define a weak diffuse prior for the Normal-Wishart family with $N_0 = 0, v_0 = 0$, while S_0 and $\overline{B}_0$ are arbitrary and follow Uhlig (1994) and Uhlig (2005) with the posterior: $N_T = X'X, v_0 = T, S_T = \widehat{\Sigma}$ and $\overline{B}_T = \widehat{B}$.

Given the posterior distribution of the VAR coefficient, we could simply investigate the property of an unrestricted Bayesian VAR model by running

[13] Uhlig (1994) studies the properties of different priors for estimation in non-explosive univariate AR(1) time series and each candidate prior behaves closely to a diffuse (or flat) prior in practical applications. In Uhlig (2005) this point is further explored by proving that all the decomposition of Σ plus a random orthogonal matrix Q of unitary length shall lead to the identical prior distribution of the impulse matrix (defined through the impulse vector a^j).

the posterior draw of (B, Σ) for K_1 times.[14] This would also allow us to calculate the cumulative impulse responses by canonical Cholesky decomposition. However, our objective is to enforce the sign restriction for the Bayesian VAR. For this purpose it is required to assign zero weight for those arbitrary parameter S_0 and $\overline{B}_0$ in the diffuse prior which do not fulfill the sign restrictions (see Dedola and Neri, 2007).

We randomly choose an occurrence of $\left(\widetilde{B}, \widetilde{\Sigma}\right)$ from the posterior distribution, namely a random number generation from $W\left(\widehat{\Sigma}^{-1}/T, T\right)$ for $\widetilde{\Sigma}^{-1}$ and $N\left(vec(\widehat{B}), \widetilde{\Sigma} \otimes (X'X)^{-1}\right)$ for $\widetilde{B}$. For each draw k we define the set of parameters $\widetilde{B}, \widetilde{\Sigma}$ and locate the corresponding identification matrix $\widetilde{A}$. Let A_0 be any other matrix satisfying (17) such that $\widetilde{A} = A_0 Q$, where Q is a random orthogonal matrix obtained by QR decomposition such that $Q'Q = I$. We choose A_0 to be the Cholesky decomposition of $\widetilde{\Sigma}$ therefore $\widetilde{A}$ also fulfills (17) and it is the instantaneous impulse matrix we choose for the draw.

For each draw k we define the set of parameters $\left(\widetilde{B}, \widetilde{\Sigma}, \widetilde{A}\right)_k$ and calculate the cumulative responses of money and external finance premium to one standard deviation of the demand and supply shocks respectively and check if they are consistent with the sign restrictions in $\bar{A}$ with impulse response coefficient, ϕ_h. We keep all the draws that pass the sign restriction, check and discard those who do not satisfy it. We repeat the procedure until we collect K_2 valid draws $\left(\widetilde{B}, \widetilde{\Sigma}, \widetilde{A}\right)_k$, $k = 1...K_2$. In this paper we set $K_2 = 200$.

[14] In this paper we set $K_1 = 500$.

3.1 Constructing the Primitive Data Series with Money Supply or Money Demand Shocks

An additional exercise we are interested in undertaking is to uncover identified money demand and supply shocks in each of the valid draws. Such shocks $\widetilde{\varepsilon}_{j,t}$ (for $j = s, d$) can be retrieved by premultiplying the residual matrix $\widetilde{u}_t$ with the inverse of the identification matrix $\widetilde{A}^{-1}$ where $\widetilde{u}_t = Y_t - X_t\widetilde{B}$ then $\widetilde{\varepsilon}_t = \widetilde{A}^{-1}\widetilde{u}_t$. Finally for each valid draw we construct the alternative data series solely dominated by either primitive supply or demand shocks in the money market:

$$\widetilde{Y}_{j,t} = Y_t - \sum_{h=0}^{t-1} \phi_h \widetilde{\varepsilon}_{i\neq j,t-h} \quad i, j = s, d$$

which filters out from the historical data Y_t the impact of the identified shocks other than shock j.[15] So $\widetilde{Y}_{d,t} = \left[\Delta\widetilde{m}_{d,t}, \widetilde{efp}_{d,t}\right]$ denote demand shock driven series and $\widetilde{Y}_{s,t} = \left[\Delta\widetilde{m}_{s,t}, \widetilde{efp}_{s,t}\right]$ denote supply shock driven series.

The next step is to define the short-term correlation (dynamic correlation) between our decomposed data for money when the j-th shock dominates, $\Delta\widetilde{m}_{j,t}$, and actual inflation, Δp_t:

$$\widetilde{\rho}_{j,h} = \frac{cov(\Delta\widetilde{m}_{j,t}\ \Delta p_{t+h})}{\sqrt{var(\Delta\widetilde{m}_{j,t}\ )var(\Delta p_{t+h})}} \qquad h = -24, ..., 0, ..., 24, \qquad (22)$$

therefore we are considering the dynamic correlations up to 2-years monthly leads and lags.

The corresponding long-term counterpart can be defined as:

[15] As we rule out possibility of permanent impact of shocks in a stationary VAR, the shock-excluding operation turns out to be a reasonable treatment for the accounting analysis of specific shock.

$$\widetilde{\rho}_{j,H} = \frac{cov(\sum_{k=1}^{H} \Delta \widetilde{m}_{j,t+k} \ \sum_{k=1}^{H} \Delta p_{t+k})}{\sqrt{var\left(\sum_{k=1}^{H} \Delta \widetilde{m}_{j,t+k}\right) var\left(\sum_{k=1}^{H} \Delta p_{t+k}\right)}} \qquad H = 0, ..., 180 \quad (23)$$

therefore we are considering correlations up to 15 years.

The corresponding short-term and long-term correlations based on the historical data for money, Δm_t , and inflation, Δp_t, are simply:

$$\rho_h = \frac{cov(\Delta m_t \ \Delta p_{t+h})}{\sqrt{var(\Delta m_t \ )var(\Delta p_{t+h})}} \qquad h = -24, ..., 0, ..., 24$$

$$\rho_H = \frac{cov(\sum_{k=1}^{H} \Delta m_{t+k} \ \sum_{k=1}^{H} \Delta p_{t+k})}{\sqrt{var\left(\sum_{k=1}^{H} \Delta m_{t+k}\right) var\left(\sum_{k=1}^{H} \Delta p_{t+k}\right)}} \qquad H = 0, ..., 180$$

In order to assess whether money is informative for inflation when either shock (supply or demand) is dominant we plot them pairwise over short and long time horizons.[16] Similarly, we draw 68% quantile error bands for inference purpose.

4 Empirical Results

This section describes the data used, summarises the main steps in the estimation strategy described in section 2 and comments the results.[17] We

[16] In addition to short- and long-run correlation calculated from the raw data, we also convert the first-difference data back to logarithm by summing up lagged value to the beginning of observations. We therefore decompose the logarithm data using HP filter. We analyze the short-run correlation with cyclical money and long-run correlation with trend money. The advantage is to distinguish the cross-correlation over short, medium and long term. Indeed, first-difference or HP filtering for either historical data or dominant-shock alternative series are just two parallel ways of extraction of cyclical information.

[17] Further results for a Eurozone estimation from 1999 onwards are available on request.

particularly concentrate on the impulse responses derived from the Bayesian VAR with sign restrictions using monthly UK and US data for money and external finance premium from 1987 to 2008. We also present the analysis of the short-term and long-term correlation with respect to inflation of our primitive money data driven by either supply or demand shocks and the historical data for money.

4.1 Data

We run the Bayesian VAR estimation with monthly UK and US macroeconomic and money market data covering the period from February 1987 to July 2008. We are interested in the full sample results and also in the two sub samples: February 1987 to December 1997 and January 1998 to July 2008. The convenient split of the data at the midpoint allows to compare the period of central bank independence under inflation targeting in the UK and the operation of Federal Reserve policy after the Asian crisis.

Broad money for UK is the $M4$ aggregate seasonally adjusted series from the Bank of England. The US counterpart is the $M3$ aggregate seasonally adjusted series from the OECD Main Economic Indicators. The UK price level, P, is RPIX[18], seasonally adjusted series from the Office of National Statistics. The US price level is the Consumer Price Index all items, seasonally adjusted series from OECD Main Economic Indicators.

The policy rate, R_P, in the UK is bank rate and in the US the FOMC's target for the federal funds rate. The wholesale market interest rate, RIB, is the British Banker's Association (BBA) 3-month sterling London interbank offered rate (LIBOR) for UK and the 3-month dollar LIBOR, averaged of last

[18]RPIX is a measure of inflation in the United Kingdom, equivalent to the all items Retail Price Index (RPI) excluding mortgage interest payments.

five trading days in a month, for US.[19] The external finance premium, efp, is the wholesale spread $efp = RIB - R_P$, and it is defined as the difference between the interbank and the policy rate.

4.2 Estimation

In this sub-section we briefly summarize the estimation strategy as a part of the overall methodology described in section 3. As we wish to construct a stationary VAR we consider the first difference in the logarithm of money supply and the price level. We use the level of the external finance premium (EFP) to match the theoretical model we develop in section 2.

To identify the money supply and demand shocks, we follow the pure sign restriction approach suggested by Uhlig (2005). We summarise the steps of the estimation strategy outlined in section 3:

(i) We assume the unrestricted VAR(p) as in (16) for the model variables, broad money growth and external finance premium. The sample moments are reported in Table 1, the money growth and inflation rates are in annual percentage terms and the EFP as a fraction of 100 basis points. It is notable that average of both model variables and inflation decrease from the early sample to the late sample, which denotes a structural break in the full sample model, with an exception of accelerating US broad money growth. We choose the optimal lag length for the VAR by multiple criteria and report the unrestricted VAR model information and residual diagnostic checks in Table 2. The optimal lags are typically within one to two quarters, similar to that of Canova and De Nicoló (2002) versus 12 months in the non-stationary VAR

[19] This series is taken from Economagic.com. We also cross-check our results with other measures of the external finance premium, such as long term corporate spreads over benchmark government bond rates and find little difference in the results. These results are omitted from this paper but are available on request.

setting of Uhlig (2005). However, in the unrestricted VAR we obtain residuals that are normally distributed according to Jarque-Bera test statistics. We also find weak serial correlation in the residuals, up to a lag of 9 and 12 months.

(*ii*) A Bayesian VAR of the same order is fitted to the data. A weak Normal-Wishart diffuse prior is assumed for the VAR parameters and the corresponding posterior distribution is formed under the sample data. The Normal-Wishart diffuse prior is particularly suitable in our case as it is a very weak prior that permits stationary, unit and explosive roots and therefore accounts for any weak nonstationarity in the data.

(*iii*) We enforce the sign restrictions by examining draws from the posterior distribution of the VAR coefficients and checking whether the draw is accepted. We then compute the cumulative impulse responses and check whether the range of impulse response is compatible with the sign restrictions. By keeping valid draws and discarding invalid draws we collect 200 possible successful draws. A Bayesian VAR with sign restrictions is therefore estimated in each successful draw. We report in Table 2 the total draws needed to achieve the 200 successful replications. With a larger number of total draws, it is more difficult to fit the data with the sign restriction Bayesian VAR model. In each of the models we consider, the valid draw as a percentage of the total draws is usually higher than 15%.

(*iv*) Given the population of successful draws from the posterior distribution of the VAR coefficients it is straightforward to make inference on the coefficients, define the impulse responses and derive the related statistics, including the error bands for these statistics. We plot in the charts from Figure 5 to Figure 10 the 16th and 84th quantiles and also the median of the results from all the 200 draws. The error band is simply a ± 1 standard

deviation from the median.

4.3 Sign restriction findings

Figures 2 and 3 show the correlation between broad money growth and inflation for US and UK data respectively. The zero mark on the abscissa represents the contemporaneous correlation and points to the right represent the lead information money growth has for inflation and to the left the lead information that inflation has for money. Figure 2 suggests some evidence of quite a change in the dynamic correlations in the two sub-samples in the US. In the earlier period inflation and money growth look positively related to each other at leads and lags of up to one year. But in the later sample, inflation has a negative lead information for money and similarly so does money for inflation at up to one year. In the UK, Figure 3, the picture looks significantly more stable with inflation negatively leading money growth and money growth having positive leads for inflation. At face value this pattern of correlations suggests quite a different constellation of demand and supply shocks in the respective money markets and over time.

Figures 4 and 5 show the correlation between money and prices at a successively longer horizon i.e. $corr(\frac{m_{t+h}}{m_t}, \frac{p_{t+h}}{p_t})$. In the absence of velocity or liquidity shocks, we would expect the correlation to rise with horizon (see equation 15). Figure 4 shows that in the US, we find that the correlation in the latter sample does not conform very clearly to our priors, in that at longer horizons the correlation tends to go negative, which suggests quite a large increase in velocity or liquidity in the latter period. Figure 5 shows that in the UK the pattern is more in line with our priors but there is some evidence of some deterioration in the positive correlation in the latter sub-period towards the end of the sample. The pattern that emerges from the US

data again is one of volatility in the money-price correlation, particularly in the latter sample. Our next step is to try and uncover whether the change in the correlation can be attributed to some degree to either demand or supply shocks in the broad money market.

Figure 6 plots the impulse responses and the forecast error decomposition of US broad money and the EFP following the implementation of our identification scheme. A standard deviation demand shock to the broad money market is found to raise the EFP by some 8 bp and year on year growth in money by around 0.15% with the half life of the shocks estimated to be in the region of around 18 months. The lower panels suggest that demand shocks account for around 40% of fluctuations in EFP and broad money growth in this sample. A standard deviation supply shock to broad money is found to reduce the EFP by around 18 bp and increase money growth by around 0.15%. The half-life of the impact is considerably quicker with 50% of the shock dissipated in less than six months. The supply shock accounts for some 60% of the fluctuations in money growth and EFP over this sample.

Figure 7 shows comparable and similar results for the UK. Two main differences stand out. There is a larger movement in the quantity of money given a movement in the EFP in the UK, suggesting flatter demand and supply curves. This is reflected in the basic moments of the data presented in Table 1, which show that money growth is more volatile and EFP less so in the UK compared to the US. That said more of the fluctuations in the EFP and in broad money growth can be explained by supply shocks in the UK, at nearly 80% compared to 60% in the US.

Figures 8 and 9 replay the dynamic correlations from Figures 2 and 3 but with the correlation obtained from the data purged of demand and supply

shocks, respectively. So that the contemporaneous negative correlation between money and inflation in Figures 2 and 8 for the US data seem to be something we can associate with a dominance of supply over demand shocks. Similarly for the UK data there appears to be a closer fit with the data when we consider the supply shock rather than demand shock case for the dynamic correlations.

Figures 10 and 11 replay the long run correlations from Figures 4 and 5. For the US the downturn in correlation at longer horizons and particularly in the latter sub-period seems to be well explained by demand shocks rather than supply shocks. So we have a story where supply shocks in the broad money market dominate at shorter horizons but demand shocks dominate over the longer run. For the UK the results is somewhat less clear cut with possibly both and demand and supply shocks having a role to play in the longer term correlation.

4.4 Assessing Policy

Concentrating on the finding that supply shocks seem the dominant explanation for fluctuations in broad money at the monthly frequency, we can use our method to uncover whether the supply shocks have been driven more by policy rates or LIBOR. Recall that the EFP equals difference between LIBOR and policy and a supply shock reduces the spread, which may imply either or both of an increase in the policy rate or a reduction in LIBOR. We can interpret the former, a positive correlation between policy rates and money supply shocks, as a policy response and any negative correlation between supply shocks and LIBOR as an exogenous increase in money market supply of funds.

In this sense Figure 12 is very revealing. We can estimate the correlation

between our identified shocks and the LIBOR and the policy rate and plot the correlation as a kernel density. In both the full samples and the latter sample, US policy rates seem uncorrelated with the supply shocks to the money market and suggest that they emanated from the liquidity provision of the banking sector, which acted in response to a compression in financial spreads - as represented by the negative correlation in LIBOR. In the UK, Figure 13, the picture that emerges is somewhat different. In that over the full sample, the policy rate has been offsetting supply shocks as we locate a positive correlation but to some extent in the latter period, this attenuation has diminished to around 0.2 from 0.4. In both countries the correlation between the EFP and supply shocks seems to be at least as well explained by financial market interest rates, as policy alone.

5 Conclusion

It has become a truism to state that monetary policy in the period of inflation targeting began to ignore money. This paper as well as illustrating why that might be the case - there are strong demand and supply shocks emanating in money markets which make inference on the true cause of any observed perturbation difficult - offers a possible strategy that might be employed to uncover whether monetary aggregates have been driven by demand or supply shocks. By using Bayesian VAR estimation, with fairly pedestrian sign restrictions that we show can fall out of a simple analysis of money markets, we can uncover primitive demand and supply shocks in the US and UK broad money market. We find that supply shocks dominate the innovations in cost of funding and the quantity of funding and particularly strong evidence in the US that these supply shocks were more closely related to financial market driven supply of funds rather than policy-induced variation. Considerably

more work on sectoral money and individual market interest rates will be required to firm up our tentative conclusions but at a moment when financial markets seem to be frozen, it is important to try and evaluate whether (a) policy (mistake) has had any role to play in the over-reach of the financial sector. Our tentative answer is yes.

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Table 1: Descriptive Statistics of Model Variables

	Early Sample 1987:2-1997:12		Late Sample 1998:1-2008:7		Full Sample 1987:2-2008:7	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
			US			
$\Delta m_{3,t}$	0.29%	0.24%	0.51%	0.33%	0.40%	0.31%
Δp_t	0.28%	0.16%	0.24%	0.27%	0.26%	0.22%
efp_t	0.31%	0.26%	0.22%	0.27%	0.27%	0.27%
			UK			
$\Delta m_{4,t}$	0.77%	0.71%	0.71%	0.50%	0.74%	0.61%
Δp_t	0.32%	0.24%	0.21%	0.19%	0.27%	0.22%
efp_t	0.23%	0.23%	0.20%	0.23%	0.22%	0.23%

Note: The model variables we investigate include broad money growth (monthly), inflation (monthly) and external finance premium (level) on wholesale money market. The data sources are given in section 4.1. We show the mean value over the sample period and standard deviations (S.D.).

Table 2: VAR Model Estimation

Models	Lags	Resid-ACF1	Resid-ACF12	Resid-N	Total Draws
US full sample	3	0.040	0.073	0.000	743
US late sample	2	0.000	0.090	0.000	959
UK full sample	5	0.079	0.115	0.000	1174
UK late sample	2	0.037	0.023	0.000	1318

Note: The model is $(\Delta m_t, efp_{w_t})$ for each case. The column 'Lags' shows lags in VAR selected by several information criteria. 'Resid-ACF1' shows the p-value of a Null hypothesis that there is no serial correlation in residuals at lag 1. The next column show the corresponding p-value for lag 12 months. 'Resid-N' shows the p-value for a Jarque-Bera test with the Null hypothesis of normally distributed residuals. 'Total Draws' show how many random draws are needed to get valid 200 replications. The higher the total draws, the more difficult to enforce the sign restrictions.

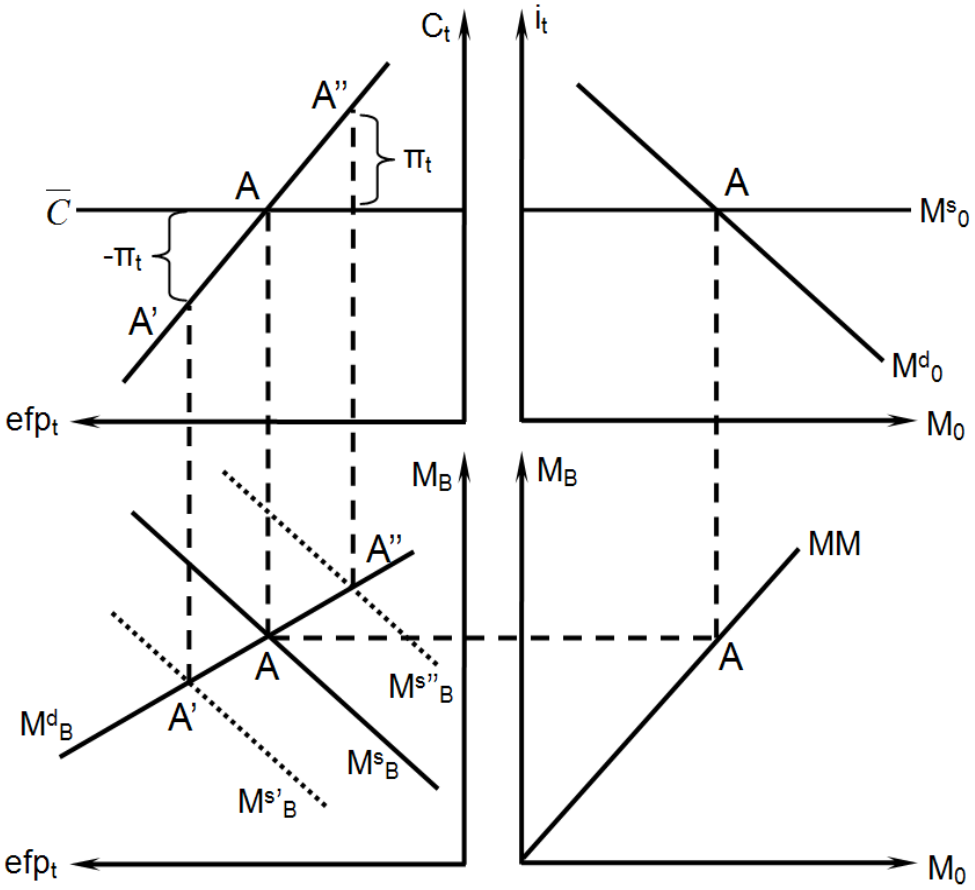

Figure 1: A simple model of money and the external finance premium

Note: The model is elaborated in section 2. In the south-east quadrant 'MM' denotes the money multiplier, which can be either constant or time-varying. In the south-west quadrant the $M_B^{s'}$ and $M_B^{s''}$ denote two alternative scenarios for the supply shocks and how they affect liquidity provision. The corresponding short-term equilibria for the money market and the aggregate economy are A' or A'', away from the initial equilibrium A.

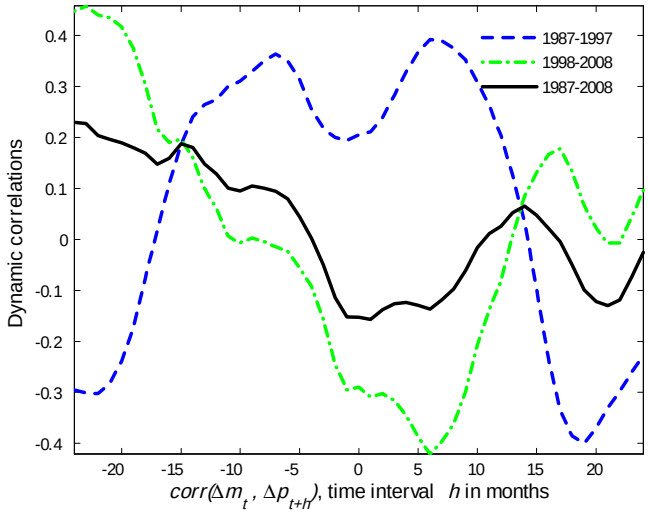

Figure 2: US dynamic correlation between money and prices

Note: Dynamic correlation between US monthly money growth and inflation. We obtain HP filtered cyclical series of each variable as the link between raw monthly growth rate is noisy. For a positive correlation with $h > 0$, money is leading inflation.

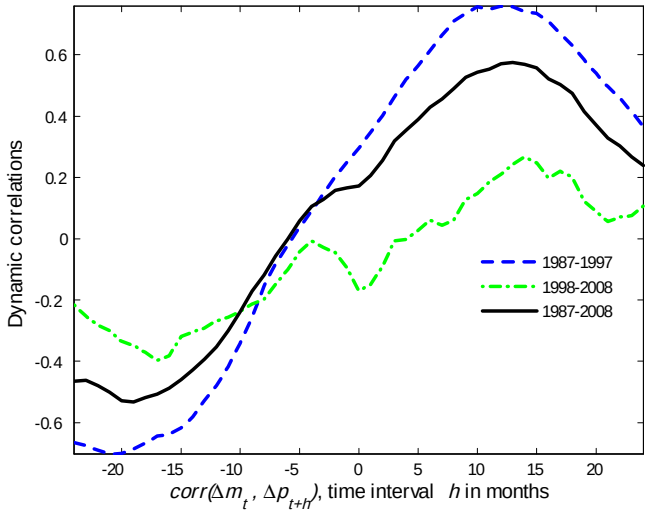

Figure 3: UK dynamic correlation between money and prices

Note: Dynamic correlation between UK monthly money growth and inflation. We obtain HP filtered cyclical series of each variable as the link between raw monthly growth rate is noisy. For a positive correlation with $h > 0$, money is leading inflation.

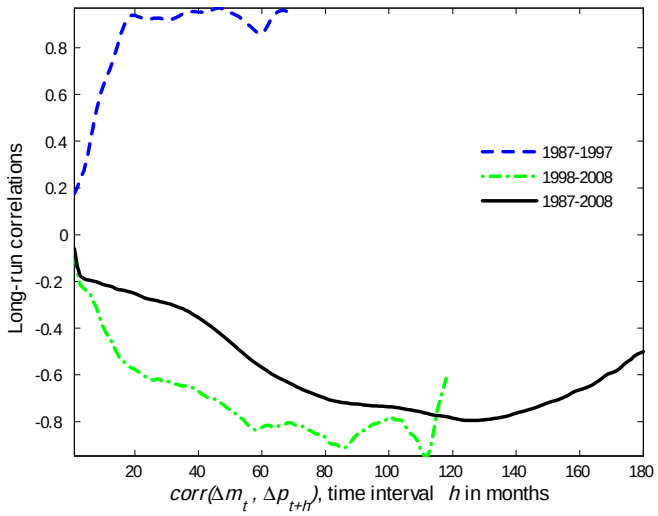

Figure 4: US long run correlation between money and price

Note: Long-run correlation between the average growth for UK money growth and inflation. We obtain original logarithm series of each variable. For an increasing positive long-run correlation we find long-run neutrality for money.

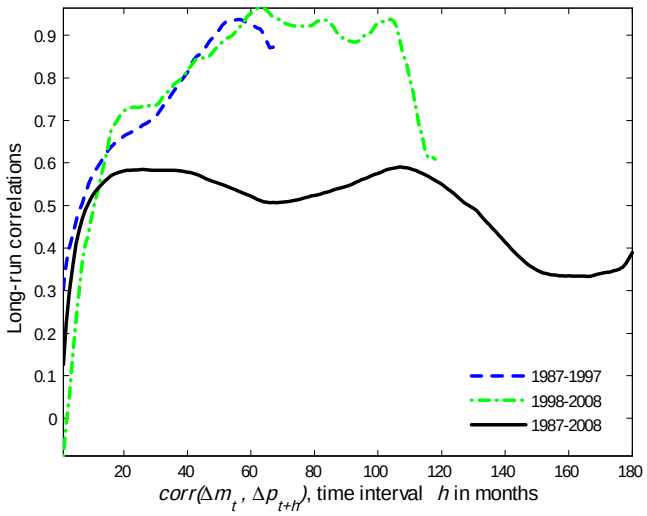

Figure 5: UK long-run correlation between money and prices

Note: Long-run correlation between the average growth for UK money growth and inflation. We obtain original logarithm series of each variable. For an increasing positive long-run correlation we find long-run neutrality for money.

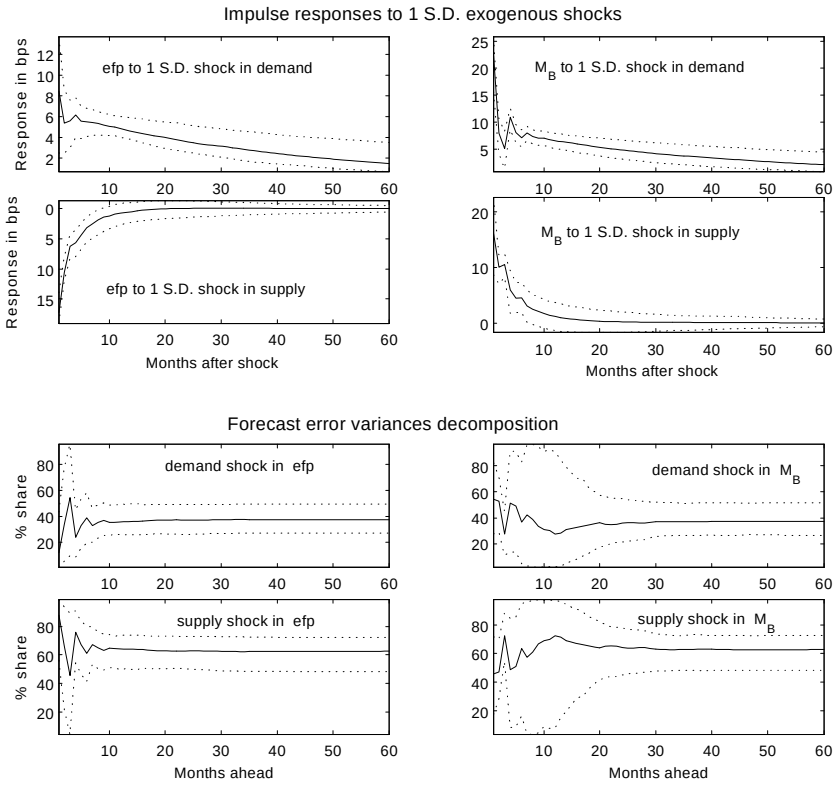

Figure 6: US VAR impulse responses with sign restriction

Note: The first and second rows show the impulse responses of the model variables to a standard deviation of demand and supply shocks in money. Sign restrictions are imposed in the first 6 months. With 200 draws from a random Bayesian VAR posterior satisfying sign restrictions, the solid line is the median response and the dotted lines are ± 1 standard errors. The third and fourth row shows the h-month ahead forecast error variance decomposition. Again, solid and dotted lines denote median and ± 1 standard errors bands, respectively.

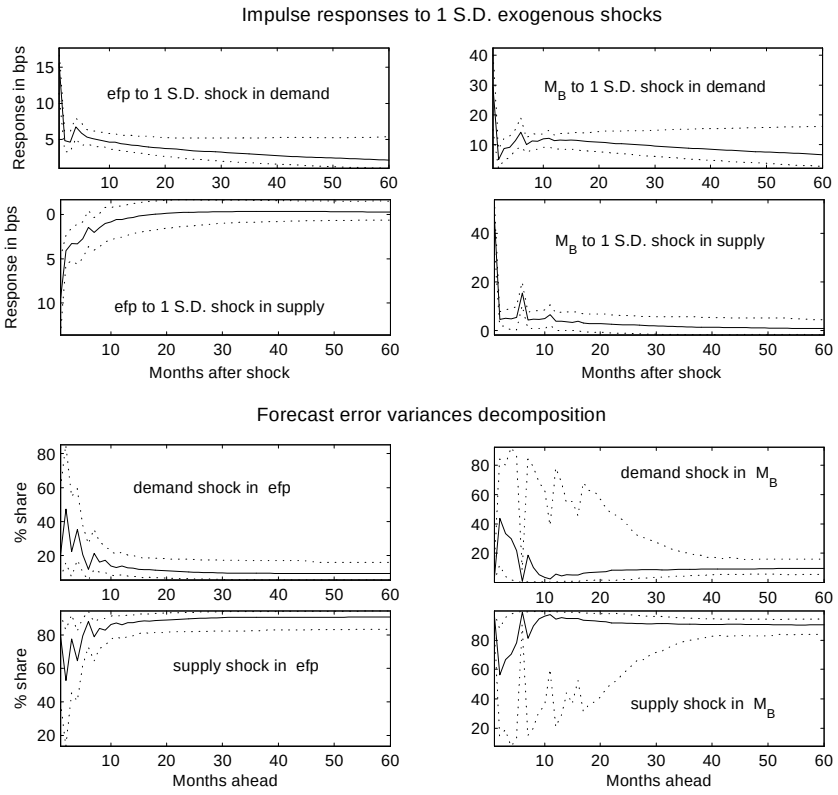

Figure 7: UK VAR impulse responses with sign restriction

Note: The first and second rows show the impulse responses of the model variables to a standard deviation of demand and supply shocks in money. Sign restrictions are imposed in the first 6 months. With 200 draws from a random Bayesian VAR posterior satisfying sign restrictions, the solid line is the median response and the dotted lines are ± 1 standard errors. The third and fourth row shows the h-month ahead forecast error variance decomposition. Again, solid and dotted lines denote median and ± 1 standard errors bands, respectively.

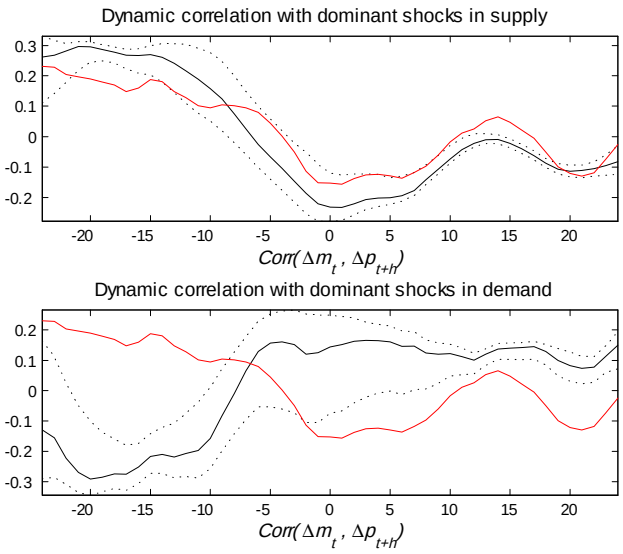

Figure 8: US dynamic correlation between inflation and supply- or demand-driven money

Note: The charts plot the dynamic correlation between the original data series and the alternative series dominated by primitive shocks in money market. The red solid line represent the actual correlation while the black solid line is the median of alternative dynamic correlations. The dotted lines are ± 1 standard errors bands.

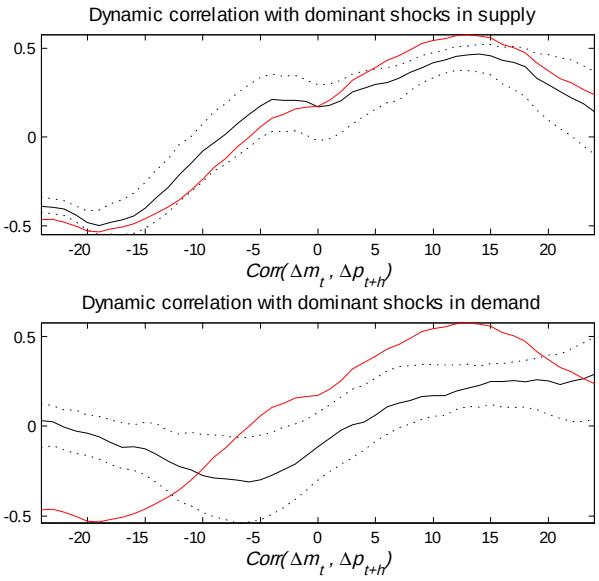

Figure 9: UK dynamic correlation between inflation and supply- or demand-driven money

Note: The charts plot the dynamic correlation between the original data series and the alternative series dominated by primitive shocks in money market. The red solid line represent the actual correlation while the black solid line is the median of alternative dynamic correlations. The dotted lines are ± 1 standard errors bands.

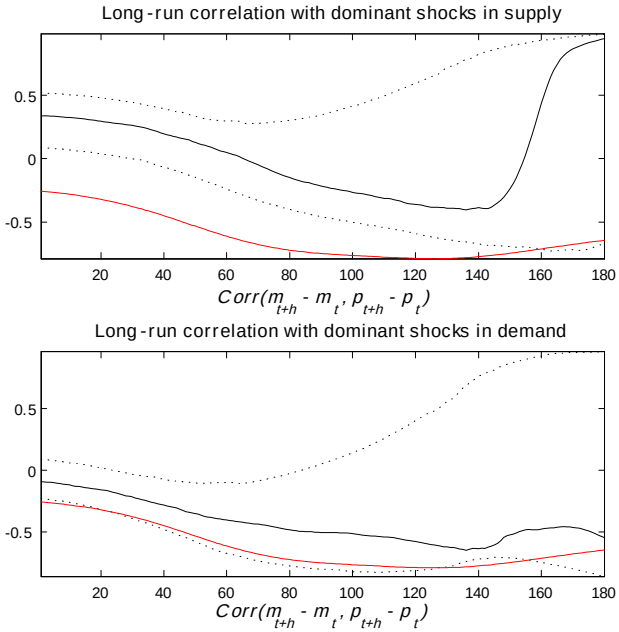

Figure 10: US long-run correlation between inflation and supply- or demand-driven money

Note: The charts plot the long-run correlation of original data series and those alternative series dominated by primitive shocks in money market. The red solid line represent the actual correlation while the black solid line is the median of alternative long-run correlations. The dotted lines are ± 1 standard errors bands.

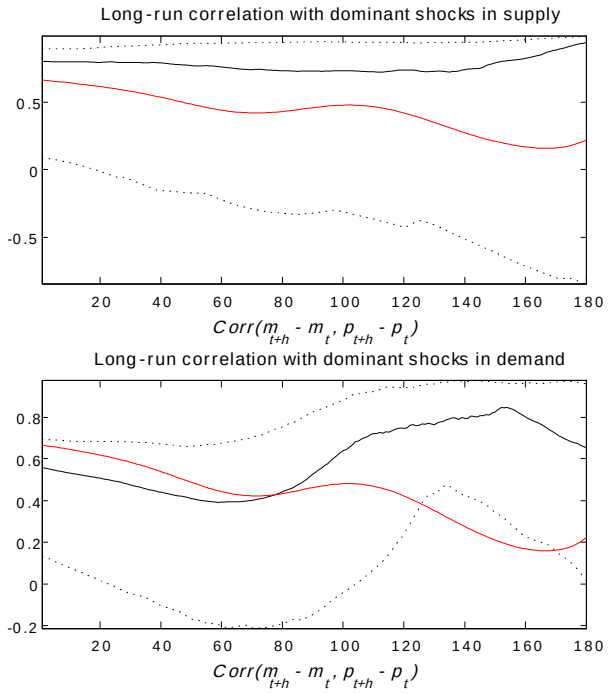

Figure 11: UK long-run correlation between inflation and supply- or demand-driven money

Note: The charts plot the long-run correlation between the original data series and the alternative series dominated by primitive shocks in money market. The red solid line represent the actual correlation while the black solid line is the median of alternative long-run correlations. The dotted lines are ± 1 standard errors bands.

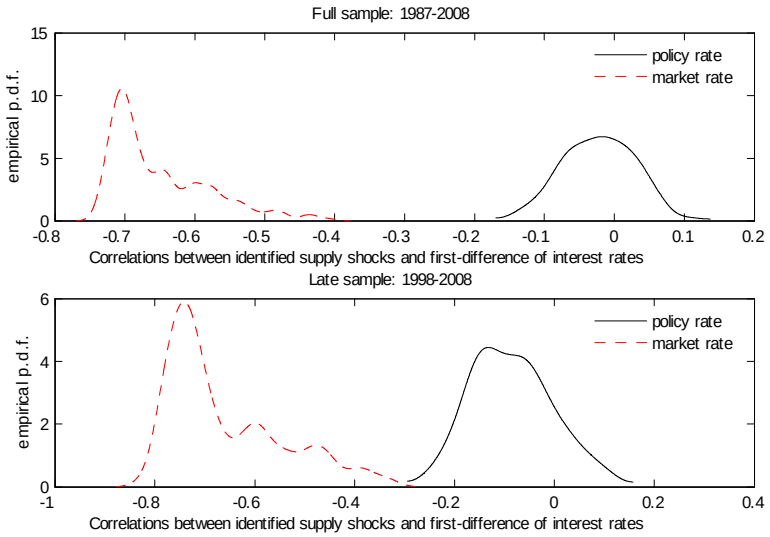

Figure 12: US money supply shock accounting

Note: The chart shows whether the identified money supply shocks are associated with changes in policy rate or market rate, the two components in the financial spread, efp. The market rate is simply the interbank rate on wholesale money market. The empirical density is the kernel density estimator from the 200 valid draws.

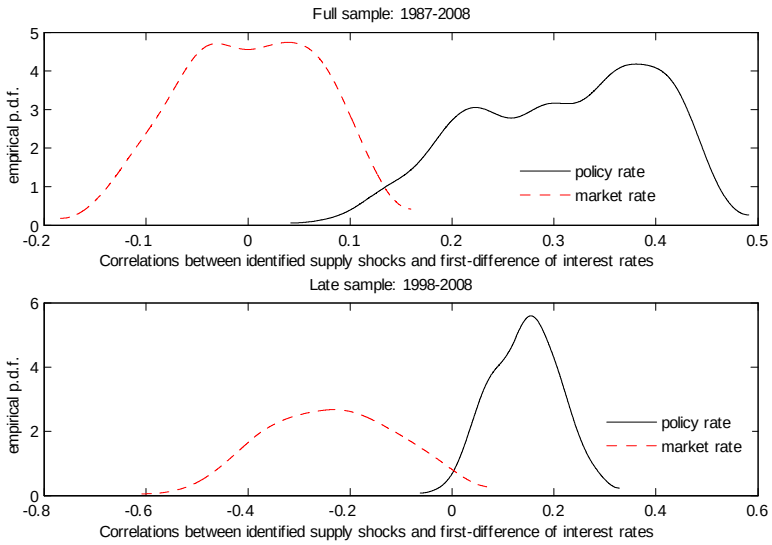

Figure 13: UK money supply shock accounting

Note: The chart shows whether the identified money supply shocks are associated with changes in policy rate or market rate, the two components in the financial spread, efp. The market rate is simply the interbank rate on wholesale money market. The empirical density is the kernel density estimator from the 200 valid draws.