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Reconsidering the role of money for output, prices and interest rates ☆

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ABSTRACT

New Keynesian models of monetary policy downplay the role of monetary aggregates, in the sense that the level of output, prices, and interest rates can be determined without knowledge of the quantity of money. This paper evaluates the empirical validity of this prediction by studying the effects of shocks to monetary aggregates using a vector autoregression (VAR). Shocks to monetary aggregates are identified by the restrictions suggested by New Keynesian monetary models. Contrary to the theoretical predictions, shocks to broad monetary aggregates have substantial and persistent effects on output, prices and interest rates.

1. Introduction

In recent years, it has become standard academic practice to discuss monetary policy without any reference to monetary aggregates. In the dominant framework—the New Keynesian monetary model—monetary aggregates do not affect any behavioral equation and the monetary authority sets the interest rate and stands ready to supply any quantity of money demanded by the market at a given interest rate. Shifts in money demand are perfectly accommodated and have therefore no effect on variables such as output and inflation. In this class of models, it is thus irrelevant to specify a traditional money demand (*LM*) equation, and money is no more than a sideshow.[1]

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[1] The redundant role of money is also a fundamental characteristic of the older Keynesian theory, as formulated in the IS–LM model. Therefore, it is not surprising that it characterizes both backward looking (e.g., Svensson, 1997; Taylor, 1999; Rudebusch and Svensson, 2002) and forward looking (e.g., Rotemberg and Woodford, 1997; McCallum and Nelson, 1999; Clarida et al., 1999; Woodford, 2003) models of monetary policy.

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The theoretical implications of excluding money from a standard monetary model with optimizing agents have been thoroughly investigated by Woodford (2003). He showed that money plays a quantitatively unimportant role in this class of models and that '...*with an interest rate rule...the equilibrium paths of inflation and output can be understood without reference to the implied path of the money supply or the determinants of money demand*.' (Woodford, 2003, Chapter 4).

Though insightful, this sharp conclusion stands in contrast with the conflicting results of a vast empirical literature. The available empirical evidence comes in two forms. The first examines the predictive content of money using *F*-tests on simple reduced form equations for output and inflation. The second relies on a more structural approach, estimating models of monetary policy with a backward looking or a forward looking structure.

Notable examples of the first approach are Friedman and Kuttner (1992) and Estrella and Mishkin (1997). They conclude that the predictive role of money for output and inflation has evaporated in the U.S. after the 1980s, due to the erratic behavior of money's velocity. These well-known results are in contrast with those of Stock and Watson (1989) and Feldstein and Stock (1993) who found that money contributes to predicting the fluctuations in output not already predictable from past values of output, prices and interest rates.

An equally opaque picture emerges from the second approach. For example, Rudebusch and Svensson (2002) fitted a small backward looking model to U.S. data and found that nominal money is not a significant determinant of output and inflation. Conversely, despite using the same model as Rudebusch and Svensson (2002), Nelson (2002) concluded that money is a significant determinant of aggregate demand (AD), both in the U.S. and in the U.K., even after controlling for the short-term real interest rate.[2] In an estimated forward looking general equilibrium model for the U.S. economy, Ireland (2004) found, instead, that real balances enter neither the AD nor the aggregate supply (AS) equations.

Other recent contributions are those in Leeper and Roush (2003) and Reynard (2007). Leeper and Roush (2003) showed that allowing the policy controlled interest rate to respond to money, rather than to output and prices—as in a standard Taylor rule—improves the identification of monetary policy shocks and eliminates the price and liquidity puzzles, often incurred in this type of empirical exercises. Reynard (2007) found that in the U.S. and the Euro area monetary developments provide qualitative and quantitative information for inflation.

The purpose of this paper is to provide new empirical evidence on the role of money for the dynamics of output, prices and interest rates, and to rationalize the conflicting results found in the literature. We begin in Section 2 by describing the class of models that gives a marginal role to monetary aggregates and show that in these models, shocks to a standard money demand equation (*LM* equation from now on) can be identified using a triangular orthogonalization of innovations in a vector autoregression (VAR), with money ordered last. Based on this result, we test the theoretical prediction that monetary aggregates are irrelevant by means of impulse responses, i.e., following an *LM* shock, responses of all variables in the VAR other than the money ought to be flat. In Section 3, we use U.S. data for the period 1966–2001 and find that this prediction is *not* empirically correct, since *LM* shocks affect the dynamic behavior of output, prices and the interest rate. We also show that our results are robust to (1) the use of different sub-samples, (2) the inclusion of additional variables that are potentially useful predictors of inflation and output, and (3) an alternative identification scheme that permits the monetary authority to react contemporaneously to changes in monetary aggregates. In Section 3, we also argue that our findings are not incompatible with results based on *F*-tests (commonly used in the literature), once it is acknowledged that if a single equation *F*-test indicates that money does not affect output (or prices), it remains possible that money has an indirect effect on output (or prices) through other variables. For this reason, we present evidence based on block-exogeneity tests, i.e., *F*-tests in a multivariate system, and conclude that money indeed has forecasting power for output and inflation. Taken together, results based on impulse responses and block-exogeneity tests cast doubts on the contention that money carries little information for the dynamics of output and inflation.

In Section 4, we ask how our results compare to structural estimates of a New Keynesian model that admits a role for money. For this purpose, we use the recent analysis of Ireland (2004) who estimated a New Keynesian model by maximum likelihood and failed to find a structural role for money. Even though it is not completely straightforward to compare our results with those of Ireland, we find that his model fails to capture a sizable effect of money on output and inflation, even when we use artificial data that assign a prominent role to money in the economy. Our interpretation is that, although money may contain information about future output and prices over and above that of current and past output and prices, the cross-equation restrictions in Ireland's model have the effect of forcing the estimate of the impact of money on other variables to zero.

Section 5 provides a tentative monetarist interpretation of our findings, and Section 6 concludes the paper with a few remarks. An unpublished supplementary empirical appendix, available on our webpages, contains the details of the robustness tests of Section 3 and further empirical results are omitted from the main body of the paper.

2. *LM* shocks: theoretical predictions

This section presents a small structural model extensively used to study monetary policy, as in Clarida et al. (1999) and Woodford (2003). The model has a forward looking structure and consists of three key equations: an AS curve

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + \varepsilon_t^s, \tag{1}$$

[2] Similar results are obtained by Meltzer (1999) and Hafer et al. (2007).

an AD curve,

$$x_t = E_t x_{t+1} - \sigma(i_t - E_t \pi_{t+1}) + \varepsilon_t^d, \tag{2}$$

and a policy rule

$$i_t = f_\pi \pi_t + f_x x_t + \varepsilon_t^p, \tag{3}$$

where $x_t \equiv y_t - y_t^n$ is the output gap (defined as the deviation of the actual output y_t from potential, y_t^n), π_t is the rate of inflation between period $t-1$ and t, and i_t is the short-term nominal interest rate and the central bank's instrument. $E_t \pi_{t+1}$ and $E_t x_{t+1}$ denote the expectations of inflation and output gap at $t+1$ conditional on information available at time t; $\beta\kappa, \sigma f_\pi$ and f_x are structural parameters and ε_t^s, ε_t^d, ε_t^p are exogenous disturbances interpretable as additional determinants of inflation, output gap and interest rate.

Eqs. (1) and (2) can be derived from microeconomic foundations: the AS curve from the optimal pricing decision of monopolistically competitive firms; the AD curve from the Euler equation for consumption of a representative utility-maximizer household. Conversely, the policy rule is postulated *ad hoc*, in the spirit of a 'Taylor rule', though the optimal reaction function of a central bank with a quadratic loss function in inflation and output gap may take a similar form (see e.g., Svensson, 1997, 2002).

One of the stark features of this simple model is the lack of reference to monetary aggregates. Subsumed in the derivation of Eqs. (1) and (2) is the assumption that the economy operates in a 'cashless limit' environment, where monetary frictions are negligible or the equilibrium money balances are sufficiently small to have no material effect on output and inflation (see Woodford, 2003). Within this framework, the levels of inflation and output are independent of the amount of real money balances in the economy and the system of Eqs. (1)–(3) is sufficient to determine the time path of the endogenous variables, $\{\pi_t, x_t, y_t, i_t\}$ given the evolution of the exogenous processes $\{y_t^n, \varepsilon_t^s, \varepsilon_t^d, \varepsilon_t^p\}$.

The same result arises if money supplies liquidity services but the household utility function is assumed to be separable in consumption and money holdings. In this case, a log-linear approximation to the first-order conditions for the representative household's optimal demand for money balances yields a conventional *LM* equation of the form

$$m_t = h y_t - \eta i_t + \varepsilon_t^{LM}, \tag{4}$$

where m_t is the level of real money balances, h and η are positive parameters and ε_t^{LM} is a disturbance which can, in principle, be correlated with disturbances affecting the AD equation.[3] Money is redundant within this class of models: the level of real money balances is demand determined, given the interest rate and the level of output, which are, in turn, determined by Eqs. (1)–(3). Hence, Eq. (4) serves the sole purpose of determining the quantity of money the central bank needs to supply to clear the money market. Since the monetary authority fixes the interest rate and accommodates shocks to the *LM* equation through passive expansions of the money supply, the equilibrium values of output, inflation and interest rate are not affected by disturbances to the *LM* curve. It is precisely for these reasons that standard New Keynesian models of monetary policy make no reference to monetary aggregates and attach no importance to the determinants of money demand or the evolution of money supply.[4]

In the remaining part of this section, we argue that this theoretical prediction can be tested using a VAR. In the following sections, we will show that this theoretical prediction is *not* empirically supported because exogenous shocks to the *LM* equation do affect the dynamics of output, prices and interest rates.

2.1. The state-space and VAR representation

Assuming that the vector of predetermined variables $\varepsilon_t' = \{y_t^n, \varepsilon_t^s, \varepsilon_t^d, \varepsilon_t^p, \varepsilon_t^{LM}\}$ follows a VAR(1) stochastic process[5] with *orthogonal* innovations $\upsilon_t' = \{\upsilon_t^n, \upsilon_t^s, \upsilon_t^d, \upsilon_t^p, \upsilon_t^{LM}\}$, the system of Eqs. (1)–(4) can be conveniently re-written in the following state-space form:

$$\mathbf{A}\begin{bmatrix} \varepsilon_{t+1} \\ E_t X_{t+1} \end{bmatrix} = \mathbf{B}\begin{bmatrix} \varepsilon_t \\ X_t \end{bmatrix} + \mathbf{C} i_t + \begin{bmatrix} \upsilon_{t+1} \\ 0_{n_X \times 1} \end{bmatrix}, \tag{5}$$

[3] In the model used by Woodford (2003, Chapters 2 and 4), for example, the residual term ε_t^l is a linear combination of preference shocks and government consumption shocks which, in his model, are shocks affecting the IS equation.

[4] This general result also holds in a model with cash in advance constraints but is no longer valid if the utility function is non-separable in money and consumption or if the liquidity services of money are modeled through the household budget constraint, as in McCallum (2002). In these last two cases, the level of real money balances matters in both the IS and the AS relation. Woodford (2003) and McCallum (2002) argued, however, that even within these more realistic models, the importance of real money balances is negligible when the parameters are calibrated on U.S. data. In the remaining sections, we will restrict our attention to the case where the underlying household utility is additively separable between consumption and real balances. This special class of utility functions enables us to isolate LM shocks and evaluate their effects on output, prices and interest rates.

[5] The analysis is easily generalized to any finite lag length.

with

$$\varepsilon_t = \begin{bmatrix} y_t^n \\ \varepsilon_t^s \\ \varepsilon_t^d \\ \varepsilon_t^p \\ \varepsilon_t^{LM} \end{bmatrix}, \quad X_t = \begin{bmatrix} y_t \\ \pi_t \\ m_t \end{bmatrix}, \quad v_t = \begin{bmatrix} v_t^n \\ v_t^s \\ v_t^d \\ v_t^p \\ v_t^{LM} \end{bmatrix}.$$

In Eq. (5) **A**, **B** and **C** are matrices of coefficients; ε_t is a $(n_\varepsilon, 1)$ vector of predetermined and exogenous variables, with ε_0 given; X_t is a $(n_X, 1)$ vector of forward looking variables; v_t is a $(n_\varepsilon, 1)$ vector of *orthogonal* innovations, with a diagonal covariance matrix, and i_t—the policy instrument—is a linear function of predetermined and forward looking variables

$$i_t = -\underset{1\times(n_\varepsilon+n_X)}{\mathbf{F}} \begin{bmatrix} \varepsilon_t \\ X_t \end{bmatrix}. \tag{6}$$

We have placed money (m_t) last in vector X_t and the orthogonal innovation to the *LM* equation (v_t^{LM}) last in vector v_t. This ordering reflects the fact that money does not enter any of Eqs. (1) and (2) nor the interest rate rule (3). The consequence of this ordering is that the **A** and **B** matrices have the following form (with $n = n_X + n_\varepsilon$):

$$\left[\begin{array}{c|c} \mathbf{A}_{(n-1)\times(n-1)} & \begin{matrix} 0 \\ \vdots \end{matrix} \\ \hline 0_{1\times(n-1)} & 0_{1\times 1} \end{array}\right] \quad \left[\begin{array}{c|c} \mathbf{B}_{(n-1)\times(n-1)} & \begin{matrix} 0 \\ \vdots \end{matrix} \\ \hline b_{1\times(n-1)} & b_{1\times 1} \end{array}\right], \tag{7}$$

such that the first $n-1$ entries of the last column of **A** and **B** are zero. Moreover, the non-zero entries in the last row of **B** allow for the possibility that the disturbance to the *LM* equation (ε_t^{LM}) is a linear combination of all disturbances affecting the AD and AS equations.[6]

Using standard methods (see, e.g., Söderlind, 1999), the solution to (5) can be written as

$$\varepsilon_{t+1} = \underset{(n_\varepsilon\times n_\varepsilon)}{\mathbf{\Lambda}} \varepsilon_t + v_{t+1}, \tag{8}$$

$$Y_t = \begin{bmatrix} i_t \\ X_t \end{bmatrix} = \underset{(n_{X+1})\times n_\varepsilon}{\mathbf{\Gamma}} \varepsilon_t. \tag{9}$$

This means that the stacked vector (Z_t) comprising the variables of interest—potential output, the control variable and endogenous variables—can be expressed as a linear function of predetermined variables:

$$\underset{(n_Z\times 1)}{Z_t} = \begin{bmatrix} y_t^n \\ Y_t \end{bmatrix} = \begin{bmatrix} \mathbf{\Lambda}_1 \\ \mathbf{\Gamma} \end{bmatrix} \varepsilon_t = \underset{(n_Z\times n_\varepsilon)}{\mathbf{P}} \varepsilon_t, \tag{10}$$

where $\mathbf{\Lambda}_1$ is the first row of $\mathbf{\Lambda}$, and $n_Z = n_\varepsilon$. Since the matrices $\mathbf{\Lambda}$ and $\mathbf{\Gamma}$ depend on the matrices of the structural parameters (**A**, **B** and **C**), $\mathbf{\Lambda}$ and **P** take a well-defined form, where the last column consists of zeros, with the exception of the last entry:

$$\mathbf{\Lambda} = \left[\begin{array}{c|c} \Lambda_{(n_\varepsilon-1)\times(n_\varepsilon-1)} & \begin{matrix} 0 \\ \vdots \end{matrix} \\ \hline \lambda_{1\times(n_\varepsilon-1)} & \lambda_{1\times 1} \end{array}\right], \quad \mathbf{P} = \left[\begin{array}{c|c} P_{(n_{Z-1}\times n_{\varepsilon-1})} & \begin{matrix} 0 \\ \vdots \end{matrix} \\ \hline p_{1\times(n_\varepsilon-1)} & p_{1\times 1} \end{array}\right]. \tag{11}$$

2.2. Implications

We now discuss how the form of the $\mathbf{\Lambda}$ and $\mathbf{\Gamma}$ matrices helps us evaluate the consequences of shocks to the *LM* equation. First, notice that the dynamics of the variables of interest, i.e., the vector Z_t, can be examined through a VAR model. Eq. (10) can be used to express (8) in terms of Z_t only

$$Z_t = \mathbf{P\Lambda P}^{-1} Z_{t-1} + \mathbf{P} v_t, \tag{12}$$

which is a standard reduced form VAR(1) representation:

$$Z_t = \mathbf{T} Z_{t-1} + u_t. \tag{13}$$

In this VAR

$$\mathbf{T} = \mathbf{P\Lambda P}^{-1}$$

[6] The zeros in the last row of the **A** matrix instead arise because the LM Eq. (4) is static. A more elaborated version of this equation involving leads and lags of money holdings (possibly derived from portfolio adjustment costs) will not invalidate the results that follow.

is the matrix of the reduced form coefficients and

$$u_t = \mathbf{P}v_t \tag{14}$$

are the reduced form residuals with variance–covariance matrix given by

$$\mathbf{\Omega} = E(u_t u_t') = \mathbf{P}E(v_t v_t')\mathbf{P}' = \mathbf{P}\mathbf{P}'. \tag{15}$$

Second, recalling that money is ordered last in Z_t, Eqs. (11) and (14) imply that the idiosyncratic innovation to the *LM* equation (v_t^{LM}) can easily be identified through a Cholesky decomposition of the variance–covariance matrix $\mathbf{\Omega}$.

Third, the restrictions on $\mathbf{\Lambda}$ and $\mathbf{P}$ imply that the first $n_Z - 1$ elements of the last column of $\mathbf{T} = \mathbf{P}\mathbf{\Lambda}\mathbf{P}^{-1}$ are zero. It follows that the impulse response functions

$$Z_{t+s} - E_t Z_{t+s} = \sum_{j=0}^{s-1} \mathbf{T}^j \mathbf{P} v_{t+s-j}$$

of all variables in Z_t except for money, to *LM* shocks (the last element of the vector v_t), will be flat at all horizons.[7]

Summarizing, the predictions concerning the effects of shocks to the *LM* relation in a standard New Keynesian model can be evaluated using an empirical VAR model, with output, output gap (or potential output), inflation, interest rate and money. The prediction that money is irrelevant for output and inflation determination can then be tested in two steps. First, *LM* shocks are identified through a Cholesky decomposition, ordering money last in the VAR. Second, following a shock to the *LM* equation, the impulse response functions are compared with the prediction that these are zero at all horizons for all variables other than money.

How general is the procedure? It turns out that it is not only valid for the model sketched in Eqs. (1)–(4), but also applicable to a larger class of models. Models with richer dynamics or models with no forward looking structure—such as those used in Svensson (1997), Taylor (1999) or Rudebusch and Svensson (2002)—can still be cast in the same state space representation as that in (5). The implications discussed above still apply, insofar as money does not appear in any structural equation, including the central bank reaction function.

3. *LM* shocks: evidence from a recursive VAR

To test the prediction of flat responses to *LM* shocks, we estimate a VAR on quarterly U.S. data for the period 1966:1–2001:3. As suggested by the New Keynesian framework, our benchmark VAR includes output, output gap, a price index, a short interest rate and money.[8] In contrast with the empirical literature on monetary policy, we do not include a commodity price index to avoid 'the price puzzle'. For reasons explained in Giordani (2004), a commodity price index is not needed if the VAR includes a good measure of the output gap, as explicitly suggested by theory.[9]

In our VAR, the federal funds rate is the policy instrument, and based on the results of the previous section, shocks to the *LM* equation are identified by a Cholesky decomposition of the reduced form covariance matrix, with money ordered last. This identification imposes that *LM* shocks have no effect on any variable (other than money) within the period. The remaining shocks are left unidentified and the ordering of the other variables is irrelevant for evaluating the effects of a shock to the *LM* equation. The VAR is estimated with four lags.

The estimated impulse response functions of all variables to an *LM* shock are plotted in Fig. 1. Contrary to the prediction of the theory, the responses of all variables are sizeable and significantly different from zero for several quarters. Output and the output gap display a hump-shaped response, reaching a peak after 4 quarters. The price index reacts strongly and persistently: after the first period, the response remains highly significant for a four-year horizon. At that horizon M2 and CPI have both increased by approximately the same amount.

A notable feature of Fig. 1 is that the federal funds rate's response is positive, significant and prolonged. This finding does not have a straightforward interpretation, however. It could reflect the endogenous response of policy—via a Taylor-type policy rule—to increases in inflation and output following a shock to monetary aggregates. Alternatively, it may represent the direct policy response to monetary aggregates innovations, or a combination of both effects. We briefly consider these alternative interpretations in Section 3.1.4.

Next, we examine the relative contributions of *LM* shocks to the variance of the *k*-step-ahead forecast errors in prices, output, output gap and federal funds rate. The results are reported in Table 1. *LM* shocks are a large source of disturbance for the price index, accounting for 23% of its forecast variance after 8 quarters and 43% after 16 quarters. The contribution of *LM* shocks to the variance decomposition of the output gap and output is smaller but not negligible; it is around 20% and 13%, respectively, after 16 quarters, and somewhat larger than the contribution of monetary policy shocks.[10]

[7] Recall that because m_t is the last variable in the VAR, the last column of the matrices $\mathbf{T}^j\mathbf{P}$ contains the impulse vector to an LM shock.

[8] The VAR includes a measure of the output gap (capacity utilization in the manufacturing sector), real GDP (logged), CPI (logged), the federal funds rate, and M2 (logged). All data are from the FRED database.

[9] None of the results depend, however, on the exclusion of a commodity price index.

[10] In our Cholesky decomposition, monetary policy shocks were identified by ordering the federal funds rate after the output gap, real output and the price index, but before money.

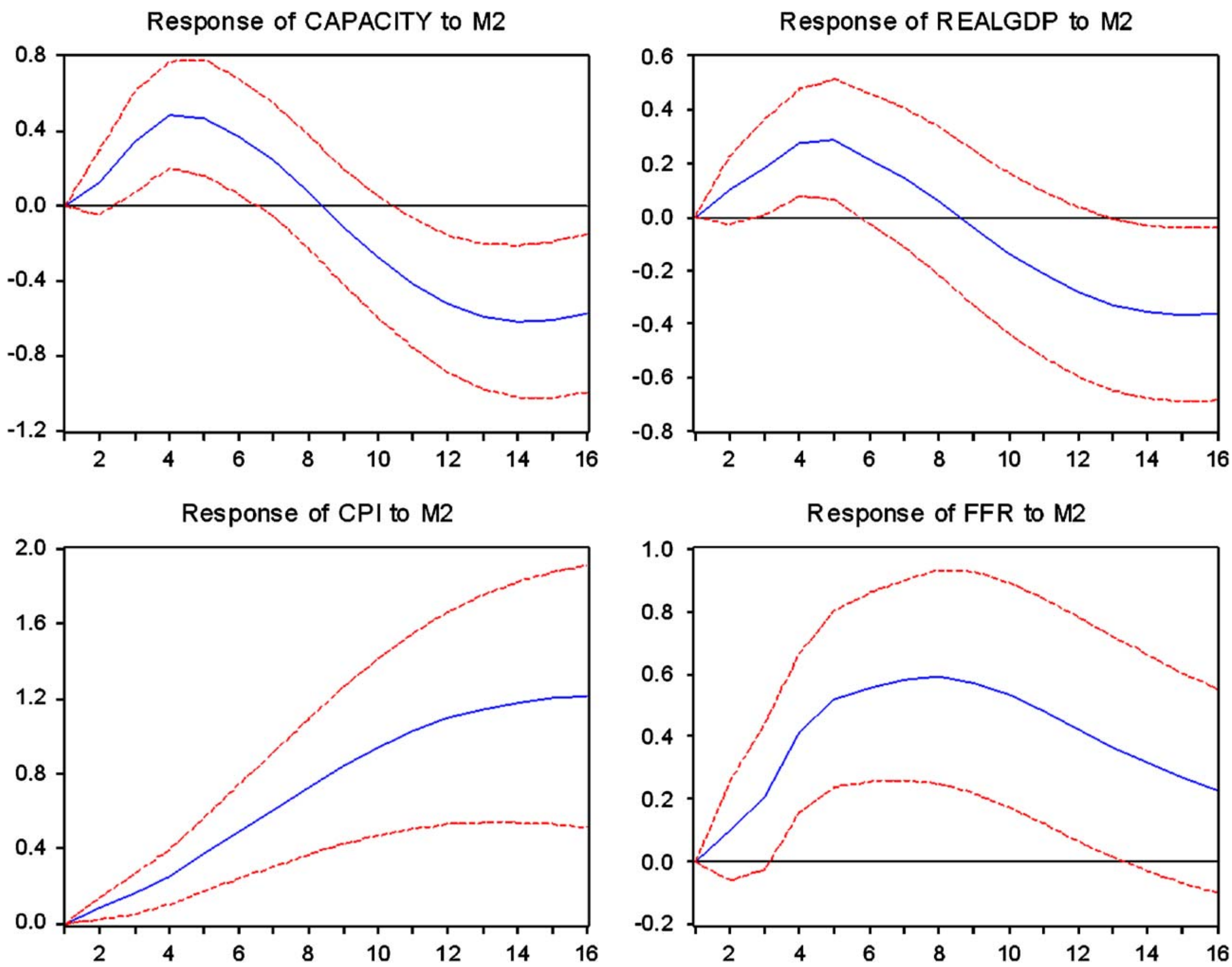

Fig. 1. Impulse response functions (with 95% error bands). The impulse responses are computed using a VAR(2) during the period 1966–2001. SPREAD refers to the 3 months minus the 10 years interest rate differential; PDRATIO is the price dividend ratio; PCOMCEE denotes a commodity price index; EXC is the U.S. dollar effective exchange rate.

Table 1
Variance decomposition benchmark VAR(4) sample period: 1966:1–2001:3.

Period	Capacity	Real GDP	CPI	FF rate	M2
0	0	0	0	0	82
2	4	3	4	2	65
4	12	7	10	11	59
8	10	5	23	24	54
16	20	13	43	32	51

Note: % of forecast error variance due to LM shocks.

3.1. Robustness of the results

We conducted several experiments to check the robustness of our results to sub-sample stability, other measures of prices and money, the inclusion of additional financial and real variables, and alternative identifications of *LM* shocks. The details of these experiments are reported in the supplementary empirical appendix to this paper,[11] and unequivocally indicate that our core results are indeed robust, if we use a broad measure of money. We briefly summarize the findings in this subsection.

[11] This appendix is available on our own webpages.

3.1.1. Sub-sample stability

If we estimate the VAR over the period 1980–2001 the impulse responses are less precisely estimated, but there is no change in our qualitative *and* quantitative results. The main difference is that the variance of *LM* shocks is smaller in this sub-sample. This is often taken as evidence that the predictive content of changes in money balances has evaporated in the last two decades. While popular, this interpretation fails to acknowledge that the variance of all shocks, and not just money, is smaller than in the full sample (a well-known fact of the so-called 'great moderation') and that each variable is less responsive to all but its own shock. While small sample bias may be responsible, at least partially, for these findings, we notice that the predictive content of money balances is not statistically insignificant in the sample post 1980 if we use, as an alternative to impulse response functions, a block-exogeneity test (see Section 3.2).

3.1.2. Alternative variable specifications

We have also estimated our benchmark VAR using (1) the GDP deflator rather than CPI and (2) annual inflation and real money balances rather than the price level and nominal money. In all cases, the responses of all variables to *LM* shocks are essentially unaltered. In addition, we experimented with alternative measures of money, namely M3, M1 and M0. Interestingly, with a narrow definition of money the responses of output, prices and the interest rate are less precisely estimated, and moreover the response of output is negative. This evidence suggests that the way money is measured is important for the robustness of our results.[12]

3.1.3. Omitted variables

The most important robustness test arguably refers to the inclusion of additional variables in the VAR. If some omitted variable had forecasting power for both money and other variables in the VAR, its omission might erroneously lead to the conclusion that money is not redundant, because it could act as a proxy for the omitted variable. To our benchmark VAR we have thus added, one at a time, real and financial variables that previous works have identified as useful predictors of inflation and economic activity (see the survey of Stock and Watson, 2003), or that it could be included in our VAR based on simple extensions of the New Keynesian framework of Section 2. In all cases M2 was ordered last in the VAR.

As financial variables, we included a (1) long-term interest rate, (2) term spread, (3) default spread, (3) stock return, (4) dividend yield; (5) exchange rate and (5) a composite index of leading indicators of inflation. Our benchmark results, however, remain virtually unaffected to the inclusions of these variables. Similar conclusions arise when we added other real variables as potentially important determinants of AD and inflation, namely (1) private investment, (2) government consumption, (3) wages and (4) unemployment.

3.1.4. Alternative identification of LM shocks

In our benchmark VAR, the identification scheme used to isolate *LM* shocks does not allow the monetary authority to react to monetary aggregates within the period. Should this assumption be incorrect, the *LM* shocks retrieved by the Cholesky decomposition could confound *LM* and monetary policy shocks. To control for this possibility, we used the benchmark VAR as in Section 3 while allowing the monetary authority to respond to monetary aggregates within the quarter. Specifically, we imposed that (1) the interest rate responds contemporaneously to the output gap (but not to output), money and prices and (2) money responds contemporaneously to output (but not to the output gap), interest rate and prices—as in a conventional money demand equation. These two restrictions, which provided a way of distinguishing monetary policy shocks from *LM* shocks, were not rejected (at the 5% significance level), and the estimated contemporaneous coefficients all had the predicted sign: the federal funds rate responds positively to both prices the output gap, and the demand for money depends positively on the level of real output and negatively on the nominal interest rate. The impulse response functions of this identified VAR following an *LM* shock remain, however, indistinguishable from those of an exactly identified triangular VAR.[13]

3.2. F-tests and block-exogeneity tests

So far, we have discussed the empirical relationship between monetary aggregates, output and prices by means of impulse response functions. A more traditional approach, extensively used in the empirical literature, is to perform *F*-tests on reduced form equations. This literature is large but has not reached any definitive conclusions.

[12] This evidence complements the results of Leeper and Roush (2003) and Hafer et al. (2007) who also noticed that broad monetary aggregates behave differently than narrow measures of money, in terms of the predictive content for output and prices.

[13] Two additional results are worth mentioning, both reported in the supplementary empirical appendix. First, when M2 was included in the VAR, the response of output following a monetary policy shock was somewhat larger than in a VAR without money. Moreover, the persistence of the interest rate shocks was much lower. These results confirm the findings of Leeper and Roush (2003) that money affects the estimated impact of monetary policy shocks. The second important result is that impulse responses to an LM shock remained almost unchanged if we used the same contemporaneous restrictions as those used above plus the additional constraints that lags of output and money do not enter the interest rate equation. This last finding suggests that the bulk of movements in the interest rate, following an LM shock, seems to reflect mainly the response of the monetary authority to output and inflation.

For example, using a bivariate VAR, Christiano and Ljungqvist (1988) found that M1 helps in predicting nominal GDP. Stock and Watson (1989) reached similar conclusions after controlling for inflation and interest rates. Conversely, Bernanke and Blinder (1992) showed that interest rates absorb the predictive power of money (M1 and M2) for output and prices in a multivariate system. Friedman and Kuttner (1992) and Estrella and Mishkin (1997) argued that the predictive content of monetary aggregates (monetary base, M2 and M1) for inflation and output has diminished since the 1980s, due to the erratic behavior of velocity. Opposite conclusions arise in Feldstein and Stock (1993), who showed that money (M2) is a significant forecaster of nominal GDP. More recently, Hafer et al. (2007) found that M2 has explanatory power for the U.S. output gap even in samples post 1980.

How can we reconcile our results based on impulse response function with the contrasting evidence based on single equation *F*-tests? Following Lutkepohl (1993, Proposition 2.2), one can show that a necessary and sufficient condition for the impulse responses to an *LM* shock to be zero is that money does not Granger-cause the *set* of remaining variables in the VAR system. Testing money's redundancy based on impulse response functions is thus equivalent to testing that the other variables in the system are block-exogenous with respect to money, i.e., that money does not help improve the forecast of *any* other variable in the system at *any* horizon. Single equation *F*-tests, however, cannot be interpreted as tests of block-exogeneity if the system of interest contains more than two variables. For example, suppose we estimate a system including inflation (π), money (m) and output (y). If we regress π on lags of itself and lags of m and y, and find that all lags of m are redundant, this result implies only that m does not help in forecasting π one step ahead. But it does not prevent m

Table 2
Block-exogeneity for **M2**.

	Sample period			
	1966:1–2001:3		1980:1-2001:3	
	p-Value	*p*-Value corr.	*p*-Value	*p*-Value corr.
	Benchmark VAR			
Levels and diff	0.024	0.073	0.001	0.017
Levels	0.000	0.003	0.001	0.016
	Benchmark + long interest rate			
Levels and diff	0.003	0.023	0.000	0.018
Levels	0.000	0.002	0.000	0.012
	Benchmark + default spread			
Levels and diff	0.065	0.211	0.000	0.020
Levels	0.000	0.001	0.001	0.026
	Benchmark + S and P500			
Levels and diff	0.057	0.182	0.001	0.029
Levels	0.023	0.095	0.001	0.028
	Benchmark + commodity price index			
Levels and diff	0.035	0.144	0.000	0.000
Levels	0.000	0.000	0.000	0.000
	Benchmark + investments			
Levels and diff	0.009	0.052	0.001	0.033
Levels	0.000	0.003	0.000	0.001
	Benchmark + government consumption			
Levels and diff	0.001	0.007	0.001	0.039
Levels	0.000	0.001	0.000	0.001
	Benchmark + wages			
Levels and diff	0.037	0.135	0.001	0.042
Levels	0.015	0.069	0.000	0.016
	Benchmark + unemployment			
Levels and diff	0.006	0.038	0.000	0.014
Levels	0.003	0.023	0.000	0.000

Note: *p*-Values are from a chi-squared distribution, with and without the conservative correction suggested by Sims (1980). Benchmark VAR includes output gap, real output, prices and interest rate. The null is that the block of variables are exogenous for M2. Under the row labeled levels, all variables are estimated in levels. In the rows labeled levels and diff the interest rates and capacity are in levels and all other variables are in first difference.

from being helpful in forecasting π through y at longer horizons, unless we can also show that all lags of m are redundant in the y equation (i.e., that m does not help in predicting y one step ahead). We conduct such a test in Table 2, where we report p-values for the null hypothesis that variables in several VARs are block-exogenous with respect to M2. In the upper panel, the test is conducted for the benchmark VAR(4) of Section 3, estimated both with all variables in levels and with real GDP, CPI and M2 in differences. The lower part of the panel considers alternative VARs that include some of the additional variables discussed in Section 3.1.3. The p-values are typically small, and importantly the null of block-exogeneity is always rejected at 5% on the 1980–2001 sub-sample.[14] Thus, the overall evidence from block-exogeneity tests helps explain why impulse response functions and single equation F-tests may produce different results.

4. Estimation of a New Keynesian model

In this section we relate our VAR findings to the structural estimates of a New Keynesian model that assigns a role to money for the dynamics of output, prices and interest rates. For this purpose, we consider the recent analysis of Ireland (2004), who studied a set-up where the representative household's utility function is non-separable in consumption and money holdings. Ireland derived the cross-equation restrictions for money to enter the AS and the AD equations. However, when estimated by maximum likelihood, Ireland's model suggests that real balances are absent from the IS and Phillips curves.[15] Even though Ireland's framework does not fall in the class of models discussed in Section 2, we find it instructive to study why his conclusions differ from ours. We will argue that Ireland's estimates cannot be taken as definitive evidence against the role of money in the economy since, depending on parameter restrictions, the same model also predicts implausible costs of nominal price adjustments and a trivial interest rate elasticity of output. We will also show that even if we generate artificial data from a VAR in which money contains important information about future output and prices, the estimates of Ireland's model recover no effect of money demand shocks.

4.1. Ireland's model

The model in Ireland (2004) is similar to the one discussed in Section 2, with the difference that real money balances, m_t, affect directly both inflation, π_t, and output, y_t, as follows:

$$\pi_t = \beta E_t\pi_{t+1} + (\psi/\omega_1)y_t - (\psi\omega_2/\omega_1)(m_t - \varepsilon_t^{LM}) + \varepsilon_t^s,$$

$$y_t = E_t y_{t+1} - \omega_1(i_t - E_t\pi_{t+1}) + \omega_2[(m_t - \varepsilon_t^{LM}) - (E_t m_{t+1} - E_t\varepsilon_{t+1}^{LM})] + \varepsilon_t^d.$$

Here, β is the discount factor, ψ refers to the cost of nominal price adjustment for a monopolistically competitive firm, ω_1 is the representative household's intertemporal elasticity of substitution, and ω_2 determines the importance of money for output and inflation. Ireland's model also includes a static money demand equation

$$m_t = \gamma_1 y_t - \gamma_2 i_t + \gamma_3\varepsilon_t^{LM},$$

where parameters γ_1, γ_2 and γ_3 satisfy the following restrictions:

$$\gamma_1 = (i - 1 + yi\omega_2/m)(\gamma_2/\omega_1) \quad \text{and} \quad \gamma_3 = 1 - (i-1)\gamma_2.$$

The model is closed with the assumption that the monetary authority follows a Taylor-type interest rate rule

$$i_t = \rho_i i_{t-1} + \rho_x y_{t-1} + \rho_\pi\pi_{t-1} + \varepsilon_t^p.$$ [16]

4.2. Model's estimates

Ireland reports that a full maximum likelihood estimation produces unreasonable estimates of the behavioral parameters of the model. Therefore, he estimates the model but constrains the coefficient of relative risk aversion to one, $1/\omega_1 = 1$, and the cost of price adjustment for goods producing firms to $\psi = 0.1$. His main findings are that (i) money has no effect on any variable in the model ($\widehat{\omega}_2 = 0.00$); (ii) real money demand depends on the interest rate ($\widehat{\gamma}_2 = 0.72$), but not on output ($\widehat{\gamma}_1 = 0.01$); and (iii) the monetary authority responds to inflation ($\widehat{\rho}_\pi = 0.56$), but not to output ($\widehat{\rho}_x = 0.00$).

[14] The p-values are from a chi-square distribution, with and without the conservative correction suggested by Sims (1980). The VAR is also estimated in first differences to account for the potential problem that F-tests take a non-standard distribution if variables have unit roots (see Sims et al., 1990). The reason the null of block-exogeneity for M2 is strongly rejected on the sample 1980–2001 while on the same sample impulse responses functions to M2 shocks are less precisely estimated is that confidence bands for impulse responses are computed pointwise: i.e., test whether there is a significant effect to a variable j at horizon h, rather than at *any* horizon, which is instead what block-exogeneity tests do.

[15] Andres et al. (2005) reached identical conclusions using a similar model and a similar estimation technique on Euro data. For consistency with the results of the previous sections, we compare our findings with those of Ireland, who estimated the model on U.S. data.

[16] The exogenous disturbances $\varepsilon_t^s, \varepsilon_t^d, \varepsilon_t^p, \varepsilon_t^{lm}$ follow $AR(1)$ stochastic processes with autoregressive parameters $\rho_s, \rho_d, \rho_p, \rho_{lm}$ and error variances $\sigma_s^2, \sigma_d^2, \sigma_p^2, \sigma_{lm}^2$.

A zero value of ω_2 is difficult to reconcile with our results based on impulse responses and block-exogeneity tests. In addition, Ireland's estimates of the remaining parameters are in disaccord with conventional estimates of the money demand equation (see Lucas, 2000; Ball, 2001) and of the Taylor rule (see Woodford, 2003, Chapter 1). Since Ireland reports difficulties in estimating all parameters, we find it informative to re-estimate his model using the same dataset and the same sample period, but a different set of parameter restrictions.[17]

In one exercise we constrained the coefficients of the Taylor rule[18] and estimated the main behavioral parameters in the AD and AS equations. In line with Ireland's findings, our maximum likelihood estimates suggest that money is irrelevant ($\widehat{\omega}_2 \approx 0$).[19] However, our estimates also suggest two important anomalies: the degree of risk aversion is unreasonably high ($1/\widehat{\omega}_1 \approx 20$) and firms face extremely large costs of nominal price adjustment ($\widehat{\psi} \approx 0$). It, thus, seems that the maximum likelihood estimation of the model fails to recover reasonable values of the model's main parameters: not only output is independent of both money *and* the real interest rate but also inflation is unrelated to output.[20]

Given these results we conjectured that Ireland's model might not be able to capture sizable effects of money on output and inflation, even if such effects were to exist. To check the validity of this conjecture we run one experiment using artificial data. Specifically, we generated 1000 observations from a VAR(2) estimated on the same sample as Ireland's. To artificially inflate the role of money, we multiplied by 2 the coefficients attached to lags of money in the inflation, output and interest rate equation. This *ad hoc* procedure attributed unrealistically large effects of *LM* shocks on all variables. However, despite the inflated role of money in the artificial data, the maximum likelihood estimate of ω_2 remained identical to zero, casting doubts on the model's potential ability to capture substantial effects of money on output and inflation.[21]

Our interpretation of these findings is that the maximum likelihood estimation of a New Keyesian model—in which money has a structural role only because the marginal utility of consumption depends on real money balances—cannot be taken as definitive evidence against the importance of money in the economy. Indeed, depending on the specifications, the model's estimate suggests also a negligible interest rate elasticity of output and implausible costs of nominal price adjustment. In other words, all the essential ingredients of a New Keyesian framework become dubious determinants of output and inflation. Furthermore, the fact that money plays no role in this model, even if by construction this role is large, suggests that the framework may be inadequate in capturing different channels through which money affects the economy.

5. A monetarist interpretation of *LM* shocks

If a New Keynesian model—like the one used by Ireland—that assigns a direct role to money in the AD and AS equations cannot rationalize the empirical results in Section 3, how can we explain the sizeable and significant effects of money demand shock? Nelson (2002, 2003) has recently argued that money may contain information about future output and prices even within a New Keyesian framework with a recursive money demand equation. In the spirit of the traditional monetarist account, he argued that money may act as proxy for various yields that drive AS. In the baseline New Keynesian model the short-term nominal interest rate is the only relevant yield for money demand and AS. However, in a more elaborated model a larger set of yields (e.g., long-term yields, equity returns, exchange rates, and yields on durable goods, etc.) can enter both the IS and the *LM* equations. In such a model, movements in money balances, not associated with changes in real output and the short-term interest rate, are not uninformative noise. Rather, these changes contain information about the multiplicity of observable and unobservable yields that directly affect AD.

Although our empirical strategy cannot be used to directly test the monetarist view, our baseline findings do not seem inconsistent with this interpretation. Additional evidence in this regard is presented in Fig. 2. It shows impulse response functions from a VAR(4), including M2 and a host of yields other than the short-term interest rate: a term spread (3 months–10 years), the dividend–price ratio, a composite index of leading indicators for inflation and output, and an effective exchange rate index. In this VAR, M2 is placed last so that it is allowed to depend contemporaneously to all these variables.

Fig. 2 displays two noteworthy results. First, regardless of which financial variables is shocked, the responses of output, the price index and the interest rate are qualitatively strikingly similar to those following an *LM* shock. Thus an increase in money, in excess of what is predicted by a standard money demand equation, seems to have the same effects as when the term spread widens, the stock return increases or the exchange rate depreciates. The similarities in the impulse responses suggest that money may indeed serve as a proxy for these alternative yields. Second, even though M2 is ordered last in our VAR, the impulse responses to an *LM* shock remain sizeable, are more persistent and more precisely estimated than the response to shocks to other financial variables. This additional result is surprising as one would expect M2 to play a minor

[17] We thank Peter Ireland for providing his data and the estimation code.

[18] Following Clarida et al. (2000) and Woodford (2003), the coefficients of the Taylor rule were fixed at $\rho_i = 0.7$, $\rho_x = 0.12$, $\rho_\pi = 0.45$.

[19] For convenience, we report the detailed set of results in the supplementary empirical appendix.

[20] Similar anomalies were detected with an alternative estimation exercise that constrained the main parameters estimated by Ireland, i.e., γ_2 and ω_2. With $\gamma_2 = 0.5$—using the estimates of Lucas (2000) and Ball (2001)—and $\omega_2 = 0.02$—as suggested by Woodford (2003, Chapter 4)—the estimated coefficient of risk aversion was still high ($\widehat{\omega}_1 \approx 8$) and the cost of nominal price adjustment unreasonably large ($\widehat{\psi} \approx 0$).

[21] A zero estimate of ω_2 was also obtained with 1000 artifical observations generated by the benchmark VAR of Section 3.

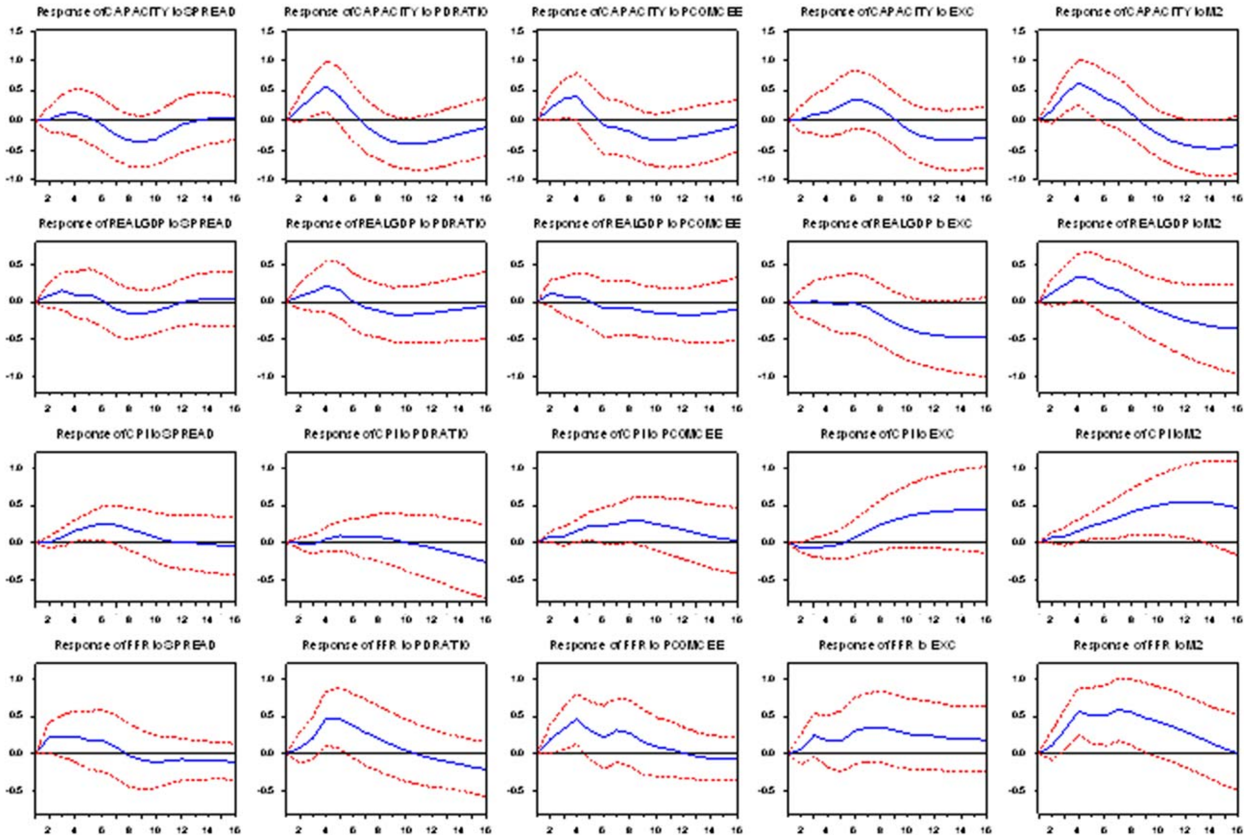

Fig. 2. Impulse response functions to *LM shocks*. The impulse responses (with 95% error bands) are computed using a VAR(4). The response of M2–M2 is omitted. The sample period is 1966–2001.

role once a large set of yields is included in the VAR. Evidently, M2 seems to act not only as a proxy for these observable yields but also as a proxy for a larger spectrum of unobservable and/or imperfectly observed yields.

Taken together, this evidence and the one presented in Section 3 suggest that an extension of the New Keynesian model that incorporates a wider range of marketable assets, along the lines pursued by Nelson (2002) or Goodfriend and McCallum (2007), is a promising research direction to account for the empirical findings of this paper.

6. Conclusion

New Keynesian models of monetary policy predict that knowledge of the quantity of money is not needed to determine the path of output, prices and interest rates. But empirical research has reached contradicting results on the role of money. While the literature works either with a specific model or with a single reduced-form equation, this paper examines the effects of shocks to monetary aggregates using an identified VAR. An important feature of our methodology is that the identifying restrictions are directly implied by a broad class of models for monetary policy analysis that only assigns a residual role to money. Contrary to the predictions of such models, our results suggest that shocks to monetary aggregates in the U.S. do contain information on the future path of output, prices and the interest rate. The results are also (1) robust to changes in the VAR specification, (2) sharper for broad monetary aggregates than for narrow measures of money, and (3) supported by a standard multivariate test of block-exogeneity.

Our findings seem to suggest that it is not innocuous to neglect broad monetary aggregates for the empirical evaluation of a small scale macroeconomic model, such as the standard New Keynesian model. Our paper, however, does not provide an alternative theoretical framework that could account for this finding, even though our results are not inconsistent with a monetarist interpretation of broad monetary aggregates as proxies for a larger spectrum of unobservable and/or imperfectly observed yields. Our hope is that further theoretical and empirical research will help account for the results of this paper.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at 10.1016/j.jmoneco.2009.01.002.

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