Reconsidering the Role of Money for Output, Prices and Interest Rates*

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Abstract

New Keynesian models of monetary policy predict no role for 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 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 and prices.

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JEL: E 31, E 52, E 58.

1 Introduction

In recent years, it has become standard academic practice to discuss monetary policy without any reference to monetary aggregates. In the dominant

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framework — the New Keynesian monetary model— 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

The theoretical implications of excluding money from a standard monetary model with optimizing agents have been thoroughly investigated by Woodford (2003). He shows that money plays a quantitatively unimportant role in this class of models and little is lost for the equilibrium determination of output and inflation if money is disregarded. He warrants 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 ch. 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 role 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 (microfounded) forward looking structure.

Notable examples of the first approach are Friedman and Kuttner (1992, 1996) and Estrella and Mishkin (1997). They provide evidence that the predictive role of money for output and inflation has evaporated in the U.S. after the 80’s, 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 find 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 (2001) fit a small structural model to U.S. data and find that nominal money is not a significant determinant of output and inflation.² Conversely, despite using the same model as Rudebusch and

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¹The 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), Ball (1997), Taylor (1999), Rudebusch and Svensson (2002) and forward looking (e.g., Rotemberg and Woodford (1997), McCallum and Nelson (1999), Clarida, Gali and Gertler (1999), Woodford (2003)) models of monetary policy.

²For similar reasons, Gerlach and Smets (1996) propose an empirical model of the
Svensson, Nelson (2000) concludes that money is a significant determinant of aggregate demand, both in the U.S. and the U.K., even after controlling for the short term real interest rate. In an estimated forward looking equilibrium model for the U.S. economy, Ireland (2004) finds, instead, that real money balances neither enter the aggregate demand nor the aggregate supply.

Other important recent contributions are those in Leeper and Zha (2000) and Leeper and Roush (2003). Leeper and Zha use a vector autoregression (VAR) analysis to conclude that the exclusion of money from this class of models is not empirically innocuous, as the interpretation of the historical policy behavior crucially hinges on the inclusion of money. Along the same lines, Leeper and Roush show 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 exercise.

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. We begin in Section 2 by describing the class of models that gives a marginal role to monetary aggregates and show that in the structure of these models, shocks to the $LM$ equation can be identified using a triangular orthogonalization of innovations in a 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 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 significantly affect the dynamic behavior of output and, to a larger extent, of inflation. We also show, in Section 4, that these results are robust to 1) sub-sample stability, 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.

Sections 5 and 6 of the paper compare our results with the relevant literature. In Section 5, we argue that our VAR findings are not incompatible with monetary transmission mechanism in the G7 countries which includes output, inflation and a short interest rate, but no monetary aggregate.

Meltzer (1999) is another example where real money affects aggregate U.S. consumption. He argues that his finding supports the validity of a real balance effect for aggregate demand. Evidence against a real balance effect in U.S. data can be found, instead, in Reifshneider et al. (1999).
the results based on $F$-tests, 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 exo-
geneity tests, i.e., $F$-tests in a multivariate system, and conclude that money
indeed has forecasting power for output and inflation. Taken together, the
coincidence of results based on impulse responses and block-exogeneity tests
seems to constitute a counter-example to the contention that money has no
role to play in the analysis of monetary policy and the economic activity.
These results suggest that money is not a nuisance variable; rather it plays
a non-trivial role in shaping the dynamic behavior of output and inflation.

In Section 6, 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 estimates a New Keynesian
model by maximum likelihood and fails to find a structural role for money.
Even though it is not completely straightforward to compare our results
with those of Ireland —due to the differences in the estimation methods—
we find that his model fails to capture a sizable effect of money on output and
inflation, even when we use artificial data with an inflated role for money.
Our interpretation is that, though based on a micro-founded analysis, 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, even if this
impact is large by construction. We draw the conclusion that although
money may contain information about future output and prices over and
above that of current and past output and prices, it is hard to recover these
effects using a tightly parametrized model such as that used by Ireland.

Section 7 concludes the paper with a few remarks.

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 aggregate supply (AS curve),

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

(1)

an aggregate demand (AD curve),

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

(2)
and a policy rule

\[ i_t = f_x \pi_t + f_x x_t + \epsilon_t^P, \]  

(3)

where \( x_t \equiv y_t - y^n_t \), is the output gap (defined as the deviation of actual output \( y_t \) from potential, \( y^n_t \)), \( \pi_t \) 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 \( t \); \( \beta, \kappa, \sigma \) are structural parameters and \( \epsilon^s_t, \epsilon^d_t, \epsilon^p_t \) are exogenous disturbances interpretable as unobservable additional determinants of inflation, output gap and interest rate.

Equations (1) and (2) can be derived from microeconomic foundations: the AS curve from the optimal pricing decision by 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, or Svensson, 2003).

One of the stark features of this simple model is the lack of reference to monetary aggregates. Subsumed in the derivation of equations (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 equations (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 \( \{ y^n_t, \epsilon^s_t, \epsilon^d_t, \epsilon^p_t \} \).

The same result arises in the more familiar environment where 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

\[ m_t = h y_t - \eta i_t + \epsilon^m_t, \]  

(4)

where \( m_t \) is the level of real money balances, \( h \) and \( \eta \) are positive parameters and \( \epsilon^m_t \) is a disturbance which can, in principle, be correlated with disturbances affecting the AD equation.\(^4\) Money is redundant within this

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\(^4\) In the model used by Woodford (2003, ch. 2 and 4), for example, the residual term \( \epsilon^p_t \)
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 equations (1)-(3). Hence, equation (4) serves the sole purpose of determining the quantity of money the central bank needs to supply to clear the money market. However, money itself has no role for the equilibrium determination of output and prices. 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.5

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 \( \epsilon'_t = \{ y^n_t, \epsilon_s^n_t, \epsilon_d^n_t, \epsilon_p_t, \epsilon_{lm}^m_t \} \) follows a VAR(1) stochastic process with orthogonal innovations \( v_t = \{ v_d^n_t, v_s^n_t, v_p_t, v_{lm}^m_t \} \), the system of equations (1)-(4) can be conveniently rewritten in the following state-space form:

\[
A \begin{bmatrix} \epsilon_{t+1} \\ E_t X_{t+1} \end{bmatrix} = B \begin{bmatrix} \epsilon_t \\ X_t \end{bmatrix} + C_i t + \begin{bmatrix} v_{t+1} \\ 0_{n \times 1} \end{bmatrix}, \quad (5)
\]

is a linear combination of preference shocks and government consumption shocks which, in his model, are shocks affecting the IS equation.

5This 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 modelled through the household budget constraint, as in McCallum (2001). In these last two cases, the level of real money balances matters in both the IS and AS relations. Woodford (2003) and McCallum (2001) argue, 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. The general purpose of our exercise is, in fact, to show that neglecting a role for money in the standard three equation model of monetary policy is not without consequences from an empirical point of view; a claim that goes beyond the general preference specification adopted to evaluate consumption and real money balances.
with

\[
\begin{bmatrix}
\epsilon_t^n \\
\epsilon_t^s \\
\epsilon_t^d \\
\epsilon_t^p \\
\epsilon_t^{lm}
\end{bmatrix}
X_t =
\begin{bmatrix}
y_t \\
\pi_t \\
m_t
\end{bmatrix}
\begin{bmatrix}
v_t^n \\
v_t^s \\
v_t^d \\
v_t^p \\
v_t^{lm}
\end{bmatrix}.
\]

In equation (5) A, B and C are matrices of coefficients; \( \epsilon_t \) is a \((n, 1)\) vector of predetermined and exogenous variables, with \( \epsilon_0 \) given; \( X_t \) is a \((n_X, 1)\) vector of forward looking variables; \( v_t \) is a \((n, 1)\) 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

\[
i_t = -\mathbf{F} \begin{bmatrix}
\epsilon_t \\
X_t
\end{bmatrix}.
\]

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 corresponds to the assumption that money does not enter any of the equations (1)-(2) nor the interest rate rule (3). The consequence of this ordering is that the A and B matrices have the following form (with \( n = n_X + n_e \))

\[
\begin{bmatrix}
\mathbf{A}_{(n-1)\times(n-1)} & 0 \\
0_{1\times(n-1)} & 0_{1\times1}
\end{bmatrix}
\begin{bmatrix}
\mathbf{B}_{(n-1)\times(n-1)} & 0 \\
0_{1\times(n-1)} & b_{1\times1}
\end{bmatrix},
\]

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 \((\epsilon_t^{lm})\) 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:

\[
\epsilon_{t+1} = \mathbf{A}_{(n_e \times n_e)} \epsilon_t + v_{t+1}
\]

\[
Y_t = \begin{bmatrix}
i_t \\
X_t
\end{bmatrix} = \mathbf{\Gamma}_{(n_X+1) \times n_e} \epsilon_t.
\]

\(^6\)The zeros in the last row of the \(A\) matrix instead arise because the LM equation (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. A detailed state space representation of the system of equations (1)-(4) is given in the Appendix.
This means that the stacked vector \((Z_t)\) comprising the variables of interest, potential output, control variables and endogenous variables, can be expressed as a linear function of predetermined variables:

\[
Z_t \begin{bmatrix} \gamma_t' \\ Y_t \end{bmatrix} = \begin{bmatrix} \Lambda_1 \\ \Gamma \end{bmatrix} \epsilon_t = \begin{bmatrix} P \end{bmatrix} \epsilon_t, \tag{10}
\]

where \(\Lambda_1\) is the first row of \(\Lambda\), and \(n_Z = n_e\). Since the matrices \(\Lambda\) and \(\Gamma\) depend on the matrices of the structural parameters \((A, B, C)\), \(\Lambda\) and \(P\) take a well-defined form, where the last column consists of zeros, with the exception of the last entry:

\[
\Lambda = \begin{bmatrix}
\Lambda_{(n_e-1) \times (n_e-1)} & 0 \\
\vdots & \ddots \\
\lambda_1 \times (n_e-1) & \lambda_1 \times 1
\end{bmatrix}, \quad P = \begin{bmatrix}
P_{(n_Z-1) \times (n_e-1)} & 0 \\
\vdots & \ddots \\
p_1 \times (n_e-1) & p_1 \times 1
\end{bmatrix}. \tag{11}
\]

### 2.2 Implications

We now discuss how the form of the \(\Lambda\) and \(\Gamma\) 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. Equation (10) can be used to express (8) in terms of \(Z_t\)

\[
Z_t = P\Lambda P^{-1}Z_{t-1} + P\nu_t \tag{12}
\]

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

\[
Z_t = TZ_{t-1} + u_t. \tag{13}
\]

In this VAR

\[
T = P\Lambda P^{-1}
\]

is the matrix of the reduced form coefficients and

\[
u_t = P\nu_t \tag{14}
\]

are the reduced form residuals with variance-covariance matrix given by:

\[
\Omega = E(u_t\nu_t') = PE(v_t\nu_t')P' = PP'. \tag{15}
\]

Second, recalling that money is ordered last in \(Z_t\), equations (11) and (14) imply that the idiosyncratic innovation to the LM equation \((\nu_{1m})\) can
easily be identified through a Cholesky decomposition of the variance-covariance matrix $\Omega$.

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

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

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.\footnote{Recall that because $m_t$ is the last variable in the VAR, the last column of the matrices $T^jP$ contains the impulse vector to an LM shock.}

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 equation (1)-(4), but also applicable to a larger class of models. In fact, models with richer dynamics or models with no forward looking structure — such as those used in Svensson (1997), Ball (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 plays a redundant role in any of these models. The crucial requirement is that money does not appear in any structural equation, including the central bank reaction function.

2.3 Discussion

The general procedure just outlined is based on the crucial assumption that $n_Z = n_e$. This assumption guarantees that $P$ is invertible and, given equation (14), there exists a mapping between reduced and structural form residuals. In words, the number of disturbances in the model (possibly including measurement errors) has to be the same as the number of endogenous variables. It thus requires that the model under consideration is correctly
specified. Whether this assumption is crucial for evaluating the importance of money is a question that deserves further discussion.

Case 1: Consider first the case where \( n_Z > n_\epsilon \). One such case (which is also the most relevant for our purpose) may arise if the disturbance to the LM equation, \( \epsilon_{lm}^t \), is a linear combination of disturbances to the other equations in the system. In this situation, the corresponding structural innovation \( v_{lm}^t \) is zero, meaning that there is no idiosyncratic shock to the LM equation and hence, the probability distribution of the vector of endogenous variables (including money) is degenerate. In fact, as can be seen from equation (14), the variance covariance matrix of the reduced form VAR (\( \Omega \)) will be singular if the variance covariance matrix of the structural innovations is singular. In practice, however, these singularities are hard to find and there is no sign of such a problem in the VARs we estimate. Thus, we believe that such a case is negligible from an empirical point of view.\(^8\)

Case 2: The case where \( n_Z < n_\epsilon \) is more problematic as it is a symptom of omitted variables. This is important for our analysis. When money is ordered last in a Cholesky decomposition, 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 (see Lutkepohl, 1993, Proposition 2.2). Testing money’s redundancy is thus equivalent to testing that the other variables in the system are block-exogenous with respect to money, i.e., money does not help improve the forecast of any other variable in \( Z_t \) at any horizon. This approach is pursued in Section 5. However, if some omitted variable had forecasting power for both money and some other variable in the VAR, its omission might erroneously lead to the conclusion that money is not redundant, because money could act as a proxy for the omitted variable. For this reason, we should make sure to investigate the sensitivity of our results to the inclusion of additional variables in the baseline model given by (1)-(4). We make this attempt in Section 4.3.

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.\(^9\) In contrast with the empirical

\(^8\)See Schorfheide (2000) for a related point.

\(^9\)The VAR includes real GDP (logged), a measure of capacity utilization in the manufacturing sector produced by the Federal Reserve Board, CPI (logged), the federal funds
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.10

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 Figure 1. Contrary to the prediction of the theory, the responses of all variables are 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 Figure 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 this problem in Section 4.4.

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. Surprisingly, 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 rate, and M2 (logged). All data are from the FRED database, aggregated from monthly data (except capacity utilization) and seasonally adjusted (except the federal funds rate).

10None of the results depend, however, on the exclusion of the commodity price index, as will be discussed in the robustness checks of Section 4.3.
4 Robustness of the results

To check the robustness of our results, we address sub-sample stability, alternative measures of prices and money, inclusion of additional variables, and identification. Figures 2a-2e report the impulse response functions to LM shocks for several specifications of the VAR, which we now discuss.

4.1 Sub-sample stability

Our sample period includes two oil shocks during the 70’s and, arguably, at least one change in the policy function of the Fed, conventionally dated around 1979 (see, for example, Bernanke and Mihov, 1998). In an attempt to control for these events, we have re-estimated the benchmark VAR over the period 1980:1-2001:3 as do Rotemberg and Woodford (1997), for example. The results are shown in the first column of Figure 2a. Although the impulse responses in the shorter sample are less precisely estimated, there is no change in the qualitative results. A closer look at impulse response functions and variance decomposition (not shown) reveals that the role of LM shocks is substantially reduced. The standard deviation of LM shocks is also smaller in the more recent sub-sample. These results seem to support the conventional wisdom that the predictive role of monetary aggregates has decreased in the last two decades. While suggestive, this interpretation fails to explain why, at all horizons, each variable in the VAR (and not just money) has a smaller variance and is less important in the variance decomposition of all variables other than itself.

Small sample bias may also be responsible for the smaller responses in the post-1980 sample. In our benchmark VAR, all variables are persistent, with CPI and M2 close to integrated of order two. Thus, the bias may be severe on the reduced sample. In fact, if the VAR is estimated using annual inflation and real money, the results are closer to those for the entire sample, though the responses remain smaller (see the second column of Figure 2a).

The sample period under consideration includes the interval 1979-1982, in which the Fed officially targeted non-borrowed reserves. Figure 2b plots the estimated LM shocks for the full sample to check if there are anomalies in

\footnote{Following a common practice in the VAR literature on monetary policy, we identify the monetary policy shock as the residual in the equation of the federal funds rate. In the Cholesky decomposition, the federal funds rate is ordered after output gap, output and the price index but before money.}
the estimated residuals. The plot reveals that the residuals do not exhibit erratic behavior, with the exception of an outlier in 1983:1. The results are unaffected if we dummy out this outlier, or if the benchmark VAR is estimated over the sample 1983:4-2001:3, as shown in the third column of Figure 2a: the effects on output gap, prices, and interest rate are unaltered.

We have also considered the effects of the break in the money demand equation that some researchers have documented for the early 90s. It turns out that for both M2 and M3, this break is less clear than for M0 and M1. A CUSUM test is passed at 5% only if a post-1990 intercept dummy (which takes the value of zero up to 1989:4 and unity thereafter) is included in the equation. Yet, augmenting the VAR with this dummy (in all equations) does not produce sizable changes as shown in the last column of Figure 2a.

4.2 Alternative variable specifications

As a further check, we adopt several VARs with alternative measures of some of the variables appearing in the baseline specification, keeping the size of the VAR constant. The results are displayed in Figure 2c. In the first column, we use the GDP deflator rather than the CPI. In the second column, we replace M2 with M3 and, in another attempt (not shown), we switch the order of interest rate and M2 in the Cholesky decomposition—though this is not justified by the model. In all cases, the responses of all variables to an LM shock are essentially unaltered. The last two columns of Figure 2c assess the effects of LM shocks using M0 or M1. For both measures of money, the responses of prices and the federal funds rate are qualitatively similar to those obtained when broader aggregates are used, albeit smaller and less precisely estimated. The responses of output gap and output, on the other hand, are never significantly positive, suggesting that the choice of a broad monetary aggregate is crucial for the results of Section 3.\footnote{The response of real GDP to M1 is anomalous, declining significantly for 15 periods after an LM shock. This result is driven by the last few years of the sample, and may be due to the well-known instability of M1. The response of GDP becomes insignificant if the VAR is estimated up to 1995.}

4.3 Additional variables

In sub-section 2.1.2, we anticipated that spurious results can be obtained if relevant variables are omitted from the VAR. Motivated by this concern, we have added several additional determinants of output and inflation to the baseline specification. The motivation is based on statistics or economics:
some of these variables are potentially useful predictors of inflation and output; others are motivated by extensions of the standard New Keynesian framework in Section 2. In all cases, M2 is ordered last. The results are reported in Figures 2d and 2e.

Financial Variables

(i) Long-term interest rate. The most immediate financial variable to consider is the long-term interest rate (the yield on 10 year government bonds). Nelson (2000) has suggested that the direct effect of real money on aggregate demand may be a proxy for an effect operating via a long interest rate. Our orthogonalization enables us to check this prediction, which implies that LM shocks have no effect on output and prices, once the long-term interest rate is controlled for. As shown in the first column of Figure 2d, the impulse responses do not support this prediction and our benchmark results remain virtually unaffected. Similar conclusions arise if a term spread is included in the VAR: neither the short end of the government bond yield curve (6-month minus 3-month) nor the spread involving a long rate (10-year minus 3-month) produce any changes worth reporting.

(ii) Bond spreads. Several papers in the literature have shown that default spreads are good predictors of output and inflation (see the extensive survey in Stock and Watson, 2001). Among others, Friedman and Kuttner (1992) have found that the spread between commercial paper and U.S. Treasury bill reduces the predictive content of monetary aggregates for output and prices. In the second column of Figure 2d, we report our set of responses after controlling for the paper-bill spread at 3-month maturity. Once again, there are no appreciable differences in the results.

(iii) Stock prices. As shown in the third column, the overall pattern of impulse responses also remains unaffected if we include an index of stock prices. In this last case, the only change worth noticing is the reduced response of prices to LM shocks. However, if an alternative measure of stock market conditions is considered, namely the log of dividend price ratio, the response of prices is again sizable and persistent (not shown).

(iv) Commodity prices. As a final check, we include the commodity price index used by Christiano, Eichenbaum and Evans (1999), a composite index of leading indicators for inflation. The inclusion of this variable also makes our benchmark VAR more in line with the standard VARs estimated in the literature on monetary policy. The last column of Figure 2d displays the results: the impulse response functions are not affected and the commodity price index rises sizably in response to an LM shock.
Non-Financial Variables

(v) Investment and government consumption. The standard framework in Section 2 is to abstract from investment and government consumption as additional determinants of aggregate demand, and from wages and unemployment as determinants of inflation. To check whether these simplifications are somehow responsible for our results, we have added investment and government consumption, both ordered in the VAR before the interest rate. As shown in columns 1 and 2 of Figure 2e, this does not produce any significant change in the benchmark responses.

(vi) Wages and unemployment. The impulse responses in the last two columns of the figure also suggest that the inclusion of wages or unemployment does not affect the overall picture of Section 3. In sum, our robustness checks indicate that unpredictable shifts in broad monetary aggregates have significant and robust effects on the dynamics of output, prices and interest rates. The effects on prices are consistently the largest.

4.4 Identification

The sample period used to estimate the benchmark VAR of Section 3 includes a long period in which the Fed adopted intermediate targets for monetary aggregates (1970-1993). Though most economists believe that monetary targets were never the most pressing concern at the Fed, we may still want to check the validity of this presumption, by including money in the central bank’s reaction function. So far, the identification scheme used to isolate LM shocks does not permit the Fed to react to monetary aggregates within the period. Though reasonable, should this assumption be incorrect, the LM shocks retrieved by the Cholesky decomposition would be likely to mix up LM and monetary policy shocks.

To control for this possibility, we identify monetary policy shocks and LM shocks without imposing that the federal funds rate does not respond to

---

13 Investment is measured as the log of total private investment, seasonally adjusted. Government consumption is the log of U.S. government consumption expenditure and gross investments, sa. Wages is the log of nonfarm business sector compensation per hour, s.a. Unemployment is the civilian unemployment rate, sa.

14 Leeper and Zha (2001) have recently argued that the fact that the Fed now ignores money does not imply that money never had a role for formulating monetary policy in the past. They present evidence for U.S. data that an interest rate rule that only responds to the growth rate of money is empirically similar to an interest rate rule that responds to inflation and output gap. Furthermore, Leeper and Roush (2003) argue that a better identification of monetary policy shocks requires the interest rate to respond contemporaneously to money rather than just to output and inflation (as in a Taylor-type interest rate rule).
monetary aggregates within the quarter. For this purpose, we use the same VAR as in Section 3 but move from a recursive (Cholesky-style) identification to structural identification. The structural model is described by:

$$\mathbf{B}_0 \mathbf{Z}_t = \mathbf{B}_1 \mathbf{Z}_{t-1} + \ldots + \mathbf{B}_1 \mathbf{Z}_{t-p} + v_t,$$

where $\mathbf{Z}'_t = \{x_t, y_t, p_t, \pi_t, m_t\}$ is the vector of endogenous variables. $\mathbf{B}_i$ are $5 \times 5$ matrices with $\mathbf{B}_0$ having unity diagonal elements, and $v'_t = \{v^d_t, v^n_t, v^s_t, v^p_t, v^{lm}_t\}$ is the vector of structural innovations with a diagonal covariance matrix. The relation between the structural innovations $v_t$ and the associated reduced form residuals $u_t$ is given by:

$$u_t = \mathbf{B}_0^{-1} v_t,$$

and the monetary policy and LM shocks are identified by imposing restrictions on the $\mathbf{B}_0$ matrix. Specifically, we impose the following: (1) the interest rate responds contemporaneously to output gap (but not to output), prices and money; (2) money responds contemporaneously to output (but not to output gap), interest rate and prices. These two restrictions (in fact either would be sufficient) provide a way of distinguishing monetary policy shocks from LM shocks, which is new in the literature. They also give us over-identification such that (one of) the restrictions can be tested. The first restriction assumes that the Fed follows a Taylor rule augmented to include the level of money. The second restriction follows from a standard money demand equation. As in the previous section, the remaining shocks are left unidentified and we only require that capacity, GDP and prices are not contemporaneously affected by monetary policy and LM shocks.

The estimated contemporaneous responses are reported in Table 2a. A few results stand out. First, the overidentifying restriction is easily accepted: the $p$-value for the associated $\chi^2(1)$ test is 0.54. Second, the estimated coefficients have the predicted sign, except that nominal money holdings do not immediately respond to prices to keep real money holdings constant. The federal funds rate responds positively to both inflation and the output gap, while demand for money increases with the level of real output and decreases with the nominal interest rate. However, the interest rate does not react positively to money: the coefficient is insignificant and has the wrong sign, suggesting that only a liquidity effect is at work. In fact, as shown in Table 2b, if we force the coefficient $B_0[4, 5]$ (the contemporaneous response of $i$ to $m$) to zero, the coefficient $B_0[5, 4]$ (the contemporaneous response of $m$ to $i$) becomes slightly larger and significant. Similar results are obtained if annual inflation and real money balances are used instead of prices and
money, and if the coefficient $B_0[4,2]$ (contemporaneous response of $i$ to $y$) is left unrestricted.\footnote{In this latter case, the estimated coefficient of $B_0[4,2]$ is not statistically significant (its $p$-value is 0.54), supporting our assumption that the monetary authority does not react to output, once we have conditioned on the output gap.}

The impulse response functions of this SVAR, plotted in Figure 3, are indistinguishable from those of an exactly identified triangular VAR. For example, the responses to an LM shock (the second column) are identical to those of Figure 1, while the responses to a monetary policy shock (the first column) are rather standard. After a contractionary monetary policy shock (a rise in the federal funds rate), the output gap has a hump-shaped response; prices initially respond very slowly but decline persistently afterwards; and money decreases upon impact and for several quarters.\footnote{See, among others, Christiano, Eichenbaum and Evans (1999) or Leeper, Sims and Zha (1996) for similar results.}

Two additional results are worth mentioning. As reported in Figure 4, no appreciable differences can be detected in the impulse response functions of output, output gap and prices following a monetary policy shock, if money is excluded from the VAR. Apparently, the inclusion of money in the VAR does not alter our inference regarding the transmission of monetary policy shocks to the economy. Rather, money seems to play an independent role for prices and output dynamics.

As reported in Figure 5, the impulse responses almost remain unchanged if we use the same contemporaneous restrictions as those used above (with $B_0[4,5]$ set to zero), plus the additional constraints that lags of GDP and M2 do not enter the interest rate equation. The impulse responses from the constrained and unconstrained SVAR are nearly identical, which cautiously suggests that a standard dynamic Taylor rule adequately approximates the monetary authority reaction function.\footnote{When we compare the unrestricted and restricted VAR with standard information criteria, both the Schwarz criterion and the Hannan and Quinn favor the restricted VAR, while the Akaike favors the uncostrained one.} This last result does not mean that there is strong evidence that the monetary authorities were not responding to money at all. But it indicates that the bulk of movements in the interest rate, following an LM shock, may simply reflect the Fed’s response to output and inflation.
5 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. We have found strong evidence that money affects the dynamics of prices and some evidence that money also influences the dynamics of output. Moreover, we have observed that these results arise if we use broad monetary aggregates (M2 or M3) rather than a narrow measure of money (M0 or M1).

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. For example, using a bivariate VAR, Sims (1972) demonstrates that money (M0 and M1) Granger causes nominal GDP. Christiano and Ljungqvist (1988) find that M1 helps in predicting nominal GDP. Stock and Watson (1989) reach similar conclusions after controlling for inflation and interest rates. Conversely, Bernanke and Blinder (1992) show that interest rates absorb the predictive power of money (M1 and M2) for output and prices in a multivariate system. Friedman and Kuttner (1992, 1996) and Estrella and Mishkin (1997) argue that the predictive content of monetary aggregates (monetary base, M2 and M1) for inflation and output has diminished since the 80’s, due to the erratic behavior of velocity. Opposite conclusions arise in Feldstein and Stock (1993), who show that money (M2) is a significant forecaster of nominal GDP, and in Cheung and Fujii (2001), who correct the tests used by Friedman and Kuttner for heteroskedasticity, and conclude that the effect of money on output becomes significant, though not sizable.

How can we reconcile our results with the contrasting evidence based on single equation $F$-tests? One problem of such $F$-tests is that they are frequently interpreted as tests of block-exogeneity, that is, as tests that “money does not help forecasting output and/or prices in a multivariate system”.

In a bivariate system with, say, inflation ($\pi$) and money ($m$), block-exogeneity can be tested by regressing $\pi$ on lags of itself and lags of $m$, and testing the null that all lags of $m$ are redundant. But a single equation $F$-test is no longer an adequate test of block-exogeneity in a system with more than two variables. If our system of equations includes an additional variable, say output ($y$), and we regress $\pi$ on the lags of $\pi$, $y$ and $m$, zero coefficients on lags of $m$ only imply that $m$ does not help forecasting $\pi$ one step ahead. But it does not prevent $m$ from being helpful in forecasting $\pi$ through $y$ at longer horizons, unless we can also show that the lags of $m$ are
redundant for $y$.\footnote{More formally, a vector of variables $Z$ is \textit{block-exogenous in the time series sense} with respect to money, $m$, if $m$ does not help improving the forecast \textit{at any horizon} of any variable in $Z$ that is based on lagged values of all elements of $Z$ alone (Hamilton, 1994, page 309). A necessary and sufficient condition for block-exogeneity is that when $m$ is ordered after $Z$ in a Cholesky decomposition, the impulse response functions of all elements of $Z$ to a shock in $m$ are flat (Lutkepohl, 1993, Proposition 2.2). This is indeed the strategy we adopted in Section 3.}

The following example illustrates the limitations of standard, single equation $F$-tests. Assume that the data generating process is given by a model which incorporates the assumption that money $m_t$ influences inflation $\pi_t$ only through its effects on output $y_t$:

\begin{align*}
\pi_t &= \pi_{t-1} + \kappa y_{t-1} + \epsilon_t^\pi \\
y_t &= \chi m_t + \epsilon_t^y \\
m_t &= \epsilon_t^m.
\end{align*}

Suppose that we estimate the following equation for the inflation rate:

\[ \pi_t = \delta_\pi \pi_{t-1} + \delta_x y_{t-1} + \delta_m m_{t-1} + \epsilon_t^\pi, \]

and run an $F$-test for the null hypothesis that $\delta_m$ is zero. Since the null is true, it is unlikely to be rejected. However, it would be wrong to infer from this $F$-test that money is not useful in forecasting inflation at \textit{any} horizon. For this conclusion to be valid, $\chi$ should also be zero. In other words, even though $F$-tests consistently concluded that money does not belong in a reduced-form equation for inflation, it would still be possible that money indirectly affects inflation through output.

In Table 3, we report $p$-values for the null hypothesis that variables in several VARs are block-exogenous with respect to M2, as suggested by New Keynesian models. 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 expanded VARs of Section 4.3 are considered in the lower parts of the panel. The $p$-values are typically small, a result in line with the impulse responses reported in previous sections.\footnote{The $p$-values are from a chi-square distribution, and from a chi-square with the conservative modification suggested by Sims (1980). The VAR is also estimated in first differences to account for the potential problem of the non standard distribution taken by the $F$-test when variables have unit roots (see Sims, Stock and Watson, 1990).} Moreover, the null of block-exogeneity is always rejected at 5\% on the 1980-2001 sub-sample.
The overall evidence from block-exogeneity tests helps explain why impulse response functions and single equation $F$-tests may produce different results.

6 Estimation of a New Keynesian Model

The objective of this final section is to relate our VAR findings to structural estimates of a New Keynesian model that assigns a non negligible role to money for the dynamics of output, prices and interest rates. For this purpose, we consider the recent analysis of Ireland (2004), who studies a set-up where the representative household utility function is non separable in consumption and money holdings. Ireland derives the necessary parameter restrictions for money to enter the aggregate supply and aggregate demand equations. But when he estimates the model by maximum likelihood, he concludes that money has no role.\footnote{Andres, Lopez-Salido and Valles (2005) reach similar conclusions using a similar model and a similar estimation technique but with Euro data. For consistency with the results of the previous sections, we compare our findings with Ireland who estimate the model on US data.} Even though Ireland’s framework does not fall in the class of models discussed in Section 2, we find it instructive to investigate why his conclusions differ from ours. We will argue that even if money contains information about future output and prices, it is hard to recover these effects by estimating a tightly parametrized model such as that used by Ireland.

**Ireland’s model** The model in Ireland (2004) is similar to the one discussed in Section 2, with real money balances, $m_t$, affecting both inflation, $\pi_t$, and output, $y_t$, as follows:

$$
\pi_t = \beta E_t \pi_{t+1} + \left( \psi / \omega_1 \right) y_t - \left( \psi \omega_2 / \omega_1 \right) (m_t - \epsilon^m_t) + \epsilon^i_t
$$

$$
y_t = E_t y_{t+1} - \omega_1 (i_t - E_t \pi_{t+1}) + \omega_2 [(m_t - \epsilon^m_t) - (E_t m_{t+1} - E_t \epsilon^m_{t+1})] + \epsilon^d_t,
$$

Here, $\beta$ is the discount factor, $\psi$ refers to the cost of nominal price adjustment for a monopolistically competitive firm, $\omega_1$ is the representative household’s intertemporal elasticity of substitution, and $\omega_2$ determines the importance of money for output and inflation.

Ireland’s model also includes a static money demand equation,

$$
m_t = \gamma_1 y_t - \gamma_2 \pi_t + \gamma_3 \epsilon^m_t,
$$
where parameters $\gamma_1$, $\gamma_2$ and $\gamma_3$ satisfy the following restrictions

$$\gamma_1 = (r - 1 + yr\omega_2/m)(\gamma_2/\omega_1),$$

$$\gamma_3 = 1 - (r - 1)\gamma_2.$$  

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

$$i_t = \rho_i i_{t-1} + \rho_x y_{t-1} + \rho_{x\pi} \pi_{t-1} + \epsilon_l^i.$$  

Ireland reports that a full maximum likelihood estimation produces unreasonable estimates of the behavioral parameters of the model. Therefore, he estimates $\omega_2$ and $\gamma_2$ but fixes 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 ($\hat{\omega}_2 = 0.00$); (ii) real money demand depends on the interest rate ($\hat{\gamma}_2 = 0.72$), but not on output ($\hat{\gamma}_1 = 0.01$); and (iii) monetary authority responds to inflation ($\hat{\rho}_\pi = 0.56$), but not to output ($\hat{\rho}_x = 0.00$).

A zero value of $\omega_2$ is difficult to reconcile with our results on block-exogeneity tests and impulse responses, however. Moreover, the estimates of the remaining parameters are in disaccord with conventional estimates of the money demand equation (see Lucas, 2000 and Ball, 2001) and of the Taylor rule (see Woodford, 2003 ch.1). Since Ireland reports difficulties in estimating all parameters, we find it informative to change the set of calibrated parameters, checking whether the model can deliver reasonable estimates of the parameters he calibrates. For this purpose, we re-estimate his model using the same data set and the same sample period, but a different set of parameter restrictions.

Our first exercise is to freely estimate the two main parameters in the aggregate demand and supply equations, i.e. $\omega_1$ and $\psi$, and instead constrain the only non-behavioral equation of the model, namely the Taylor rule. Following Clarida, Gali and Gertler (2000) and Woodford (2003), we set the coefficients of this equation to $\rho_i = 0.7$, $\rho_x = 0.12$, $\rho_{\pi\pi} = 0.45$, so that the long-run elasticity of the interest rate to inflation is above one.\footnote{The exogenous disturbances $\epsilon_s^r$, $\epsilon_d^r$, $\epsilon_l^r$, $\epsilon_l^{lm}$, follow AR(1) stochastic processes with autoregressive parameters $\rho_s$, $\rho_d$, $\rho_l$, $\rho_{lm}$ and error variances $\sigma_s^2$, $\sigma_d^2$, $\sigma_l^2$, $\sigma_{lm}^2$.} The maximum likelihood estimates are reported in the second column of Table 4a, while Ireland’s results are reproduced in the first column.\footnote{As discussed in Woodford (2003), this condition ensures the existence of a unique rational expectations equilibrium.} In line with

\footnote{We thank Peter Ireland for providing the estimation code.}
his estimates, we find that money is irrelevant. However, our estimates also suggest two important anomalies. First, the degree of risk aversion \((1/\omega_1)\) is unreasonably high; second the parameter \(\psi\) is indistinguishably different from zero. Therefore, it seems that the maximum likelihood estimation of the model fails to recover reasonable values of the model’s main parameters: not only money but also output has no effect on inflation; moreover, output seems independent of both money and the real interest rate.

Our second exercise is to freely estimate \(\omega_1\) and \(\psi\) but constrain the parameters estimated by Ireland, i.e. \(\gamma_2\) and \(\omega_2\). We set \(\gamma_2\) to 0.5 using the estimates of Lucas (2000) and Ball (2001) and \(\omega_2\) to 0.02, as suggested by Woodford (2003, Ch. 4), which implies a non-trivial role of money in the model. The third column in Table 4a reports the results. It turns out that the estimate of \(\hat{\omega}_1\) is still unreasonably low (and not statistically different from zero) and \(\hat{\psi}\) continues to be essentially zero.

Given that the model estimates suggest an implausibly small output-inflation trade-off and a negligible role of the real interest rate in the output equation, it may be conjectured that the model may not be able to capture sizable effects of money on output and inflation, even if such effects were to exist. We go some way toward confirming this conjecture with experiments on artificial data.

In one experiment, we generate 1000 observations of output, inflation, money and interest rate from a VAR(2) estimated on the same sample as in Section 3. Using this large sample of data — which minimizes small sample errors and, by construction, gives a prominent role to money — we re-estimated Ireland’s model.24 The results reported in the first column of Table 4b show, however, that the maximum likelihood estimate of \(\omega_2\) is still close to zero, implying a trivial role for money. In a second experiment, we generate 1000 observations from a VAR(2) estimated on the same sample of Ireland’s. To artificially inflate the role of money in this sample, we also multiply by two the coefficients attached to lags of money in the inflation, output and interest rate equation. On average, this triples the unconditional standard deviation of the simulated data, and the VAR impulse responses show unrealistically large effects of money demand shocks on all variables. Despite the inflated role of money in the artificial data, the maximum likelihood estimate of \(\omega_2\), reported in the second column of Table 4b, is still close to zero, casting doubts on the model’s potential ability to capture

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24In the artificial data money has a prominent role by construction in the sense that the point estimates of the VAR, used to generate the data, attribute a strong effect of money on the other variables in impulse responses and variance decomposition functions, as documented in sections 3 and 4.
substantial effects of money on output and inflation.

Why are results hard to reconcile with Ireland’s estimates? Our interpretation is that the cross-equation restrictions implied by his model are not supported by the data. The evidence presented above suggests that, though based on a micro-founded analysis, these restrictions bias the estimate of the impact of money on other variables towards zero, even if this impact is large by construction. Even though, money may contain information about future output and prices, it is hard to recover these effects by estimating a tightly parametrized model such as the one used by Ireland.

7 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 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 our 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 US do contain information on the future path of output and (especially) prices. The results are robust to changes in the VAR specification extending the basic New Keynesian model. The results are much sharper for broad monetary aggregates (M2 or M3) than for narrow money.

Our findings seem to suggest that current models of monetary policy may neglect an important determinant of output and inflation dynamics by assuming away any reference to monetary aggregates. A clear-cut prediction of widely used models for policy analysis is decisively rejected by empirical tests. Our paper, however, does not provide an alternative theoretical framework that could account for this finding. For this reason, we have deliberately chosen to dub shocks to monetary aggregates “LM shocks” and have avoided giving them a structural interpretation, even though our estimates retrieve a sensible money demand equation. A skeptical researcher may take our results to mean that money has a purely informational role as many other leading indicators of the economic activity. Empirical work alone, however, is not enough to disentangle these alternative views. Our hope is that further theoretical and empirical research will help account for
the results of this paper.

Appendix: State space representation

Consider the structural model of Section 2:

\[ \pi_t = \beta E_t \pi_{t+1} + \kappa x_t + \epsilon_t^s \]
\[ x_t = E_t x_{t+1} - \sigma (i_t - E_t \pi_{t+1}) + \epsilon_t^d \]
\[ i_t = f_i \pi_t + f_x x_t + \epsilon_t^p \]
\[ m_t = hy_t - \eta i_t + \epsilon_t^l, \]

and define with \( \epsilon_t = [y_t^n \epsilon_t^s \epsilon_t^d \epsilon_t^p \epsilon_t^l]' \) the vector of predetermined and exogenous variables, following an AR(1) stochastic process with orthogonal innovations \( v_t = [v_t^n v_t^s v_t^d v_t^p]' \). Indicating the vector of forward looking variables by \( X_t = [y_t \pi_t m_t]' \), the dynamics of the model can then be written as:

\[
A \begin{bmatrix} \epsilon_{t+1} \\ E_t X_{t+1} \end{bmatrix} = B \begin{bmatrix} \epsilon_t \\ X_t \end{bmatrix} + Ct + \begin{bmatrix} v_{t+1} \\ 0_{n_x \times 1} \end{bmatrix},
\]
\[ i_t = -F \begin{bmatrix} \epsilon_t \\ X_t \end{bmatrix}, \]

where the matrices of structural parameters \( A, B \) and \( C \) are given by

\[
A = \begin{bmatrix} I_{5 \times 1} & 0_{5 \times 3} \\ 0_{3 \times 5} & -1 & -\sigma & 0 \\ 0 & 0 & -\beta & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix},
\]
\[
B = \begin{bmatrix} \rho_n & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \rho_s & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_d & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_p & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_l & 0 & 0 & 0 & 0 \\ (1 - \rho_n) & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ -\kappa & 1 & 0 & 0 & \kappa & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & h & 0 & -1 \end{bmatrix},
\]
\[
C = \begin{bmatrix} 0 & 0 & 0 & 0 & -\sigma & 0 & -\eta \end{bmatrix}',
\]

and the policy rule \( F \) is:

\[
F = \begin{bmatrix} f_x & 0 & 0 & -1 & 0 & -f_x & -f_\pi & 0 \end{bmatrix}'.
\]

24
References


Table 1: Variance Decomposition
Benchmark VAR(4)

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Note: % of forecast error variance due to LM shocks.
Table 2a: Estimated contemporaneous coefficients
SVAR(4)
Sample period: 1966:1-2001:3

\[
\begin{pmatrix}
\times & 0 & 0 & 0 & 0 \\
\times & \times & 0 & 0 & 0 \\
\times & \times & \times & 0 & 0 \\
-0.46^{***} & 0 & -0.52^{**} & 1 & 0.22^{(0.22)} \\
0 & -0.19^{***} & 0.23^{(0.16)} & 0.14^{(0.11)} & 1
\end{pmatrix}
\begin{pmatrix}
u_x \\
u_y \\
u_p \\
u_i \\
u_m
\end{pmatrix}
= 
\begin{pmatrix}
u_t \\
u_t \\
u_t \\
u_t \\
u_t
\end{pmatrix}
\]

Note: Standard errors in parenthesis. *** denotes significance at 1% level, ** denotes significance at 5%. \( \times \) denotes freely estimated coefficients.
The p-value for the test of overidentifying restriction \( \chi(1) \) is 0.54.

Table 2b: Estimated contemporaneous coefficients
SVAR(4)
Sample period: 1966:1-2001:3

\[
\begin{pmatrix}
\times & 0 & 0 & 0 & 0 \\
\times & \times & 0 & 0 & 0 \\
\times & \times & \times & 0 & 0 \\
-0.46^{***} & 0 & -0.60^{**} & 1 & 0 \\
0 & -0.22^{***} & 0.14^{(0.14)} & 0.23^{***}^{(0.05)} & 1
\end{pmatrix}
\begin{pmatrix}
u_x \\
u_y \\
u_p \\
u_i \\
u_m
\end{pmatrix}
= 
\begin{pmatrix}
u_t \\
u_t \\
u_t \\
u_t \\
u_t
\end{pmatrix}
\]

Note: See Table 2a
The p-value for the test of overidentifying restriction \( \chi(2) \) is 0.43.
### Table 3: Block Exogeneity for M2

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<tr>
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Note: p-values are from a chi-squared distribution, and with conservative correction suggested by Sims. 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 Levels, all variables are estimated in levels. In the rows Levels and Diff the interest rates and capacity are in levels and all other variables are in first difference.
<table>
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<th>Parameter</th>
<th>Ireland Est. (s.e.)</th>
<th>ML. Est. (s.e.)</th>
<th>ML. Est. (s.e.)</th>
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<td>0.991 0.001</td>
<td>0.992 0.001</td>
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Log-Likelihood: $-1359.3$, $-1389.06$, $-1389.7$

Note: Maximum Likelihood estimation of the DSGE model of Section 6
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<td>$\beta$</td>
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<td>$\sigma_{im}$</td>
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<td>$\sigma_s$</td>
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<tr>
<td>$\sigma_r$</td>
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</table>

Note: Maximum Likelihood estimation of the DSGE model of Section 6.
Figure 1. Impulse response functions to a one-standard-deviation LM shock in the benchmark VAR(4) of Section 3, with 95% error bands (thin dashed line)
Figure 2a: Sub-sample stability. Responses to a one-std LM shock in several VAR(4). Dashed lines are 95% std error bands.
Figure 2b: LM shocks from benchmark VAR(4) of Section 3
Figure 2c: Alternative VAR specifications. Responses to a one-std LM shock in several VAR(4) Dashed lines are 95% std error bands.
Figure 2d: Financial variables. Responses to a one-std LM shock in several VAR(4)
Dashed lines are 95% std error bands.
Figure 2e. Non-financial variables. Responses to a one-std LM shock in several VAR(4). Dashed lines are 95% std error bands.
Figure 3. Impulse response functions to monetary policy shocks and LM shocks the SVAR of Section 4.4, with 95% error bands (thin dashed line)
Figure 4. Impulse response functions to a one-std monetary policy shock in the SVAR(4) of Section 4.4 (continuous line), and in a VAR(4) that excludes M2 (thick dashed line). 95% error bands (thin dashed line) refer to the SVAR. thick dashed line). 95% error.
Figure 5. Impulse response functions to monetary policy shocks and LM shocks in the two SVAR(4) of Section 4.4: with unconstrained lags (continuous line), and with no lags of GDP and M2 in the interest rate equation (thick dashed line). 95% error bands (thin dashed line) refer to the first SVAR.