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Show Me the Money

or

Taking the Monetary Implications of a Monetary Model Seriously

Abstract

It has become common practice in applied monetary economics to posit an interest rate rule, i.e. a variant of the Taylor rule, as a component of the economic environment. Since the general equilibrium settting also imposes a money demand relationship (e.g. placing real balances in the utility function or imposing a cash-in-advance setup), the interest rate rule implies that the money supply is endogenous. Rarely are the properties of the money supply implied by the model compared to the data. In this paper, we take the monetary implications of a monetary model seriously (we use a variant of the Christiano, Eichenbaum, and Evans (1997) limited participation model that permits both technology and money shocks) by first modeling the money supply as an exogenous Markov process and then calibrating the parameters of the Markov process to the data. We then examine whether the model produces an interest rate rule similar to the Taylor rule relationship observed in the data. The results from this exercise are instructive: the model is able to duplicate qualitatively the relationship between inflation and nominal interest implied by the Taylor rule but fails dramatically to replicate the correlation between nominal interest rates and output.

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1 Introduction

Applied monetary theory has recently followed the lead of most central banks by minimizing the importance of monetary aggregates. In the conduct of monetary policy, this is reflected in the fact that policy is almost entirely described and evaluated in terms of short term interest rates. Similarly, in monetary theory it is now common practice to construct economic models in which an interest rate rule, i.e the Taylor rule, is imposed while the implied behavior of the money supply is virtually ignored. While the former practice can be justified on operational grounds, the latter is potentially problematic since it ignores an important dimension of monetary models, namely, money demand, that may prove useful in assessing and comparing proposed alternative monetary frameworks. In this paper we explore this dimension within the context of a limited participation model (a variant of the model developed in Christiano, Eichenbaum, and Evans (1997)) that incorporates both money and technology shocks

An example of the current practice in monetary analysis is that of Smets and Wouters (2002). This paper examines monetary policy by estimating the parameters describing tastes and technology of a state-of-the-art monetary model using data from the Euro system and then uses these estimates to conduct welfare analysis. In their analysis, monetary policy is represented by an interest rate rule. While the model imposes a relationship between interest rates and money supply through household money demand, the implications of this relationship are not examined. The paper by Benhabib, Schmitt-Grohe, and Uribe (2001) represents another strand of the Taylor rule literature. The focus of this literature is on the stability and uniqueness of equilibrium; in the analysis, the implied path of the money supply is again relegated to the distant sidelines. [1]

Our analysis is the mirror image of these models in that we treat the money supply process as exogenous and examine the endogenous behavior of the implied interest rate rule. In doing so, we therefore examine whether the money demand relationship implied by the model is consistent with the interest rate rule observed in the data. We use the limited participation model for our analysis; this choice was based upon two factors: (1) nominal interest rates are affected by both Fisherian and liquidity factors and (2) the asymmetric impact of monetary policy (i.e. open market operations) on households vis-a-vis financial intermediaries is captured, albeit crudely. Moreover, Christiano, Eichenbaum and Evans (1997) concluded that this model, in comparison to a sticky-price model, more accurately replicated key features of the U.S. economy. The empirical test consists of calibrating the parameters of the Markov process describing the evolution of the money supply to the data (using the monetary base as the monetary aggregate) and then examining whether the model produces an interest rate rule similar to that observed during the sample period.[2]

The results from this exercise are instructive: the model is able to duplicate qualitatively the relationship between inflation and nominal interest implied by the Taylor rule but fails dramatically to replicate the correlation between nominal interest rates and output. The failure is due to the fact that monetary disturbances produce a negative relationship between

[1] It is important to note that there is a sizeable literature that does indeed take the monetary implications of monetary models seriously. Namely, the literature in which the presence of a liquidity effect is examined. Examples are: Dow (1995) and Dotsey and Ireland (1995). Our analysis is closely related to this literature but differs in that we use the Taylor rule relationship as the "stylized fact" that forms the basis for our analysis.

[2] Our analysis is quite similar to the recent work by Fève and Auray (2002). There they also use a cash-in-advance model (along with a sticky-price version) and treat the money supply as an exogenous process. Their findings show that those models, unlike the limited participation model analyzed here, can produce Taylor rule like behavior.

interest rates and output within the model while the Taylor rule states that this relationship should be positive. While technology shocks could in principle produce this positive correlation in the model, we do not find this behavior in the calibrated version. Hence, we conclude that a limited participation model that does not produce a positive relationship between technology shocks and interest rates is missing a key feature of the U.S. economy.

2 Limited Participation Model with Technology Shocks

For our analysis, we employ a variant of the limited participation monetary model described in Christiano, Eichenbaum, and Evans (1997). We simplify the analysis by assuming that output is produced in a single sector characterized by identical, perfectly competitive firms using standard technology. That is, the production function uses inputs of capital and labor and exhibits constant returns to scale; we depart, however, from the previous authors' model by assuming that production is subject to stochastic shocks.[3] There are four economic agents: households, firms, financial intermediaries, and the government. These interact in factor, goods, and lending markets. Characteristic of these models, there are four critical rigidities: (i) Households face a cash-in-advance constraint on consumption purchases. (ii) Households make portfolio decisions before they know the state of the world (i.e. the realizations of the monetary growth rate and the technology shock) which can not be revised. (iii) The monetary injection (or tax if the growth rate is negative) is distributed directly and solely to the financial intermediaries. (iv) Firms must finance their current wage bill through loans from the banking sector. These timing assumptions and the flow of funds in the various

[3] The Christiano, Eichenbaum, and Evans (1997) model includes an intermediate goods sector, comprised of monopolistic competitors and a final goods sector. The motivation for their set-up is to allow for comparison between sticky-price and limited-participation models.

markets are depicted in Figures 1 and 2. The choices of each agent are described in more detail below.

Figure 1: Timing of Markets in the Limited Participation Model

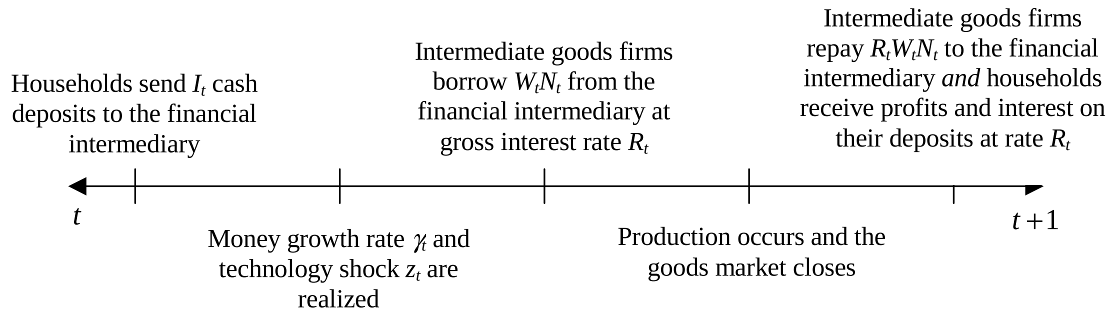
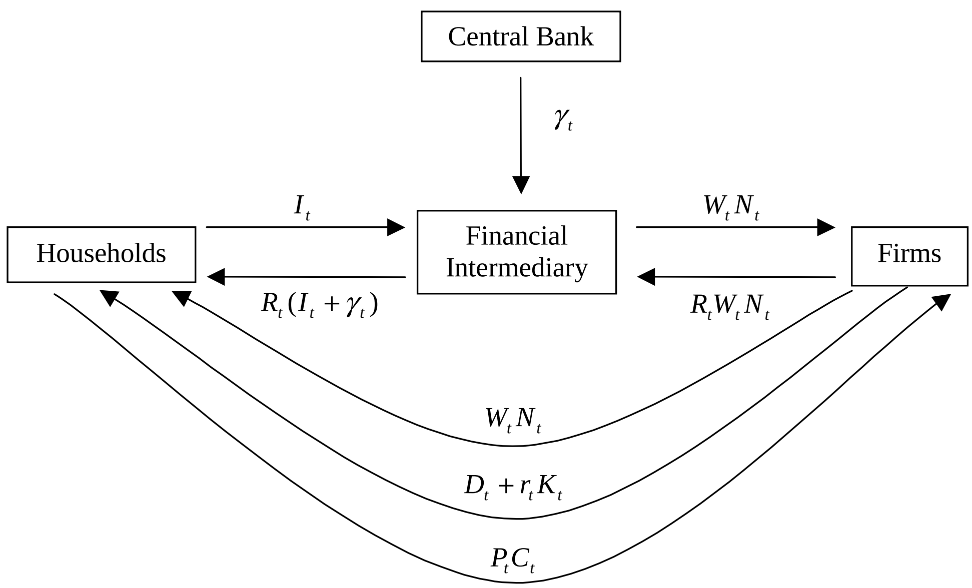


Figure 2: Flow of Funds in the Limited Participation Model



2.1 Households

In every period, identical agents choose their time t consumption, C_t, and labor hours, N_t, to maximize present discounted expected utility:

$$E_t \sum_{i=0}^{\infty} \beta^i U\left(C_{t+i}, N_{t+i}\right) \tag{1}$$

where $\beta \in (0,1)$. The utility function has the following form:

$$U\left(C_t, N_t\right) = \log\left(C_t - \frac{\psi_0}{1+\psi} N_t^{1+\psi}\right) \tag{2}$$

with $\psi_0, \psi > 0$.

In addition to labor, households sell their capital to the firms. Since our interest is in the business cycle behavior of the model, our analysis focuses on the labor market. Hence, we assume all households own one unit of capital, which is supplied inelastically to firms at the nominal rental rate r_t. Moreover, the depreciation rate is zero while output is perishable and hence only used for consumption. This implies $K_t = 1, \forall t$.

Households enter each period with cash holdings M_t and must make their portfolio decision before the current realizations of the monetary and technology shocks are known. This decision consists of allocating M_t between nominal balances to be used for consumption and deposits, denoted I_t, to the banking sector. The gross nominal return on deposits, denoted R_t, is determined after the state of the world is known and received after the goods market closes. Once the state is known, agents make consumption and labor decisions. Current nominal labor income, $W_t N_t$, is paid in advance of production and, hence, augments the nominal balances allocated for consumption. This implies the following cash-in-advance constraint on consumption purchases:

$$P_tC_t \leq W_tN_t + M_t - I_t \tag{3}$$

At the end of the period, agents receive the income from capital, the return from deposits, and the profits from the financial intermediary (these consist of the income generated by lending the monetary injection). Household money holdings are described by the following law of motion:

$$M_{t+1} = W_tN_t + M_t - I_t - P_tC_t + r_tK_t + R_t\left(I_t + X_t\right) \tag{4}$$

where X_t represents the lump-sum cash injection issued by the central bank at time t.

Given these constraints, optimal choices of labor, consumption, and deposits must satisfy the following necessary conditions:

$$\frac{W_t}{P_t} = \psi_0 N_t^{\psi} \tag{5}$$

$$E_{t-1}\left[\frac{U_{c,t}}{P_t}\right] = E_{t-1}\left\{\beta R_t E_t\left[\frac{U_{c,t+1}}{P_{t+1}}\right]\right\} \tag{6}$$

Equation (5) expresses the standard result that agents' marginal rate of substitution between consumption and labor is equal to the real wage and defines an upward sloping labor-supply curve with labor supply elasticity of $1/\psi$. The lagged expectation operator in the necessary condition associated with funds deposited in the banking sector, equation (6) , expresses the fact that this decision is made at time t before the current state of the world is known, i.e. with the information known in period $t-1$.

2.2 Firms

Firms choose labor and capital every period in order to maximize profits; the production function is assumed to be Cobb-Douglas:

$$Y_t = z_t K_t^{\alpha} N_t^{1-\alpha} \tag{7}$$

where $\alpha \in (0, 1)$. The technology shock follows a stationary first-order Markov process with unconditional mean $\mu_z = 1$; this process will be described in more detail below. Since the firms must pay workers in advance of production, they borrow their wage bill, $W_t N_t$, from a financial intermediary. These firms repay the wage bill, at gross interest rate R_t, after revenue from production is received (at the end of the period.) Firms also pay the costs of capital to households at the end of the period.

The profit maximizing choices of K_t and N_t are characterized by the condition that factors are paid their marginal products. Consequently, the labor demand curve in the economy is defined as (the equilibrium condition that $K_t = 1$ has been used)

$$R_t \frac{W_t}{P_t} = (1 - \alpha) \frac{z_t}{N_t^{\alpha}} \tag{8}$$

The labor supply and labor demand curves, i.e. equations (5) and (8) respectively, can be combined to yield the following expression characterizing equilibrium in the labor market:

$$R_t = \frac{(1 - \alpha)}{\psi_0} z_t N_t^{-(\psi + \alpha)} \tag{9}$$

2.3 Financial Intermediary

The financial intermediary in this economy provides loans to the firms using the deposits from households and new money distributed by the central bank. Banks incur no costs implying that loans are inelastically supplied to firms; the interest rate adjusts so that the following market clearing condition holds in equilibrium:

$$W_t N_t = I_t + X_t \tag{10}$$

The demand for funds derives from firms' wage bills, $W_t N_t$, which they borrow before production occurs. The demand for funds, F^D, can be expressed by using equation(8) and the corresponding necessary condition for capital $\left(r_t = \alpha z_t N_t^{1-\alpha}\right)$ to yield:

$$F_D \equiv W_t N_t = \frac{(1-\alpha)}{\alpha} \frac{r_t}{R_t} \tag{11}$$

Equation (11) expresses a static downward-sloping demand for funds in $R - F$ space. Upon payment of the loan, the financial intermediary returns $R_t I_t$ (in return for deposits) and $R_t X_t$ (as profits) to households, as described in equation (4).

The cash-in-advance constraint, equation (3), is assumed to be binding in all periods. Combining this condition with the equilibrium condition from the loan market equation (10) permits market clearing in the goods market to be expressed as:

$$P_t C_t = M_t + X_t \tag{12}$$

or, since $Y_t = C_t$ at equilibrium:

$$P_t = \frac{M_t + X_t}{Y_t} \tag{13}$$

Consequently, equilibrium velocity is always unity when defined in terms of the end-of-period money stock. Combining equations (9) and (13) yields the following expression:

$$\frac{W_t N_t}{P_t C_t} = \frac{I_t + X_t}{M_t + X_t} \tag{14}$$

This expression represents the ratio of funds passing through the loan to goods markets. Note that this ratio is monotonically increasing in the monetary transfer, X_t. The implication for nominal interest rates can be seen by using equation (8) and the resource constraint, $C_t = z_t N_t^{1-\alpha}$, to rewrite the left-hand side of equation (14) to yield:

$$\frac{(1-\alpha)}{R_t} = \frac{I_t + X_t}{M_t + X_t} \tag{15}$$

Clearly, increased liquidity in the loan market (i.e. an increase in X_t) will cause interest rates to fall.[4]

2.4 Central Bank

The sole purpose of the central bank is to provide money to the financial sector. The growth rate of money is defined as:

$$x_t \equiv \frac{X_t}{M_t} = \frac{(M_{t+1} - M_t)}{M_t} \tag{16}$$

The money growth rate, x_t, like the technology shock follows a stationary Markov process; this is described in the next section.

[4] Note that, in equation (15), both I_t and M_t are predetermined when the current value of X_t is realized.

3 Calibration

In order to solve the model, parameter values for preferences (β, ψ, ψ_0) and technology (α) are needed; in addition, the Markov process for the shocks must be specified. The preference and technology parameters are borrowed from Christiano, Eichenbaum, and Evans (1997) with the following values used: the discount factor, β, is set equal to 0.9926, the capital share α is 0.36, and the elasticity of labor supply, $\frac{1}{\psi}$, is set to 1. The parameter ψ_0 is determined such that the steady state value for labor, $\bar{N}$, is unity.

The Markov process for the money and technology shocks is assumed to be a discrete state process in which the monetary growth rate can take on three values $(x_1 < x_2 < x_3)$ while the technology shock can take on two values $(z_1 < z_2)$. Consequently, the state, $s_k = (x_i, z_j)$, $k = i, j$ with $i = 1, 2, 3; j = 1, 2$, is described by a 6-state Markov process. We calibrate the parameters of this process using quarterly data from 1959:3 to 1998:4.[5] A complete description of the data is provided in the Data Appendix.

The Solow residual is used as the measure of technology shocks. The residual is constructed from the following equation:

$$\log(SR_t) = \log(Y_t) - \alpha \log(K_t) - (1 - \alpha) \log(N_t)$$

where Y_t is real gross domestic product, K_t is the capital stock, and N_t is aggregate hours of wage and salary earners on non-farm payrolls.[6] All variables are in per-capita terms. The

[5] We also examined two sub-samples of the data that excluded the period of non-borrowed reserves targeting (i.e. 1979:3-1982:1). Results were broadly consistent across sample periods so that, in the interest of brevity, we present the full sample results only.

[6] The capital stock was calculated using the perpetual inventory method, using data from 1947:1 to 1998:4. The investment series is seasonally-adjusted fixed private nonresidential investment and quarterly depreciation is assumed to be 2.0%.

Solow residual is then linearly detrended and the technology shock, $\log(z_t)$, is measured as the detrended series.

We use the adjusted monetary base as the measure for money supply in the model. Given that the monetary base is defined as currency plus reserves, this measure of money supply most closely matches that in the model. The percentage change in the monetary base is identified as x_t.

The six possible states in each period are defined as follows:

$$\begin{array}{ll} s_1 = (x_1, z_1) & s_4 = (x_1, z_2) \\ s_2 = (x_2, z_1) & s_5 = (x_2, z_2) \\ s_3 = (x_3, z_1) & s_6 = (x_3, z_2) \end{array}$$

where x_j and z_j are the realizations of the monetary growth and technology shocks, respectively. To determine the state, we partition the data using the sample means of both shocks, $\bar{x}$ and $\bar{z}$, and standard deviation of the monetary shock, δ in the following manner:

$$s_t = \begin{array}{ll} s_1 \text{ if } (x_t \leq \frac{\bar{x}-\delta}{2} & \text{and } z_t \leq \bar{z}) \\ s_2 \text{ if } (\frac{\bar{x}-\delta}{2} < x_t \leq \frac{\bar{x}+\delta}{2} & \text{and } z_t \leq \bar{z}) \\ s_3 \text{ if } (x_t > \frac{\bar{x}+\delta}{2} & \text{and } z_t \leq \bar{z}) \\ s_4 \text{ if } (x_t \leq \frac{\bar{x}-\delta}{2} & \text{and } z_t > \bar{z}) \\ s_5 \text{ if } (\frac{\bar{x}-\delta}{2} < x_t \leq \frac{\bar{x}+\delta}{2} & \text{and } z_t > \bar{z}) \\ s_6 \text{ if } (x_t > \frac{\bar{x}+\delta}{2} & \text{and } z_t > \bar{z}) \end{array}$$

The transition probabilities are calculated using the appropriate relative frequency measure;

i.e. we use the following specification:

$$\pi_{ij} = \frac{n_{ij}}{\sum_{k=1}^{6} n_{ik}}$$

where n_{ij} is the number of times state i is followed by state j in the sample. Finally, the values for (x_i, z_j) are determined by the means of the partitioned data; e.g. x_1 is the mean of the monetary growth rate for values that satisfy $x_t \leq \frac{\bar{x}-\delta}{2}$.

To assess how well this parameterization captures the time series properties of the shocks, the implied unconditional means, standard deviations, and first-order autocorrelations of each series were computed; in addition, the contemporaneous correlations between shocks were calculated. The moments implied by the Markov process are compared to the sample moments in Table 1. The parameterization matches the moments fairly well. However, the magnitudes of the cross correlations are much weaker than observed while the autocorrelations for both shocks are slightly weaker than those observed in the data.

4 Results

Since portfolio decisions are made before the current state is known, the quantity of funds going to the financial intermediary will be a function of the state (determined by the realization of the shocks) at time period $t-1$. Hence, there will be six values for this quantity denoted $i_k = I_t/M_t$. (The nominal quantity of funds is scaled by the beginning of period money stock to achieve stationarity.) The remaining variables will be functions of both the current (denoted k') and previous state (denoted k), hence, equilibrium is determined by 36 values for labor, $N_{kk'}$, 36 interest rates, $R_{kk'}$, and 6 values for investment, i_k. These values are the solutions to 78 non-linear equations. Six equations are given by the intertemporal efficiency condition which, by using the binding cash-in-advance constraint and functional form for preferences, can be written as:

$$F_k = \beta E_k \left[\frac{R_{kk'} F_{k'}}{(1 + x_{k'})} \right] \tag{17}$$

where E_k denotes the expectations operator conditional on the state k and

$$F_k \equiv E_k \left[\frac{1}{(1 + x_{k'}) - \left(\frac{i_k + x_{k'}}{1+\psi} \right)} \right] \tag{18}$$

The market clearing condition for the labor market provides 36 additional restrictions:

$$R_{kk'} = \frac{(1 - \alpha)}{\psi_o} z_{k'} N_{kk'}^{-(\alpha+\psi)} \tag{19}$$

Finally, the ratio of funds in the goods and lending markets (equation (14)) yields an additional 36 equations which can be written as:

$$\psi_0 N_{kk'}^{\alpha+\psi} = z_{k'} \left(\frac{i_k + x_{k'}}{1 + x_{k'}} \right) \tag{20}$$

These values imply the solutions for the other variables (P_t, Y_t, w_t) in the economy where w_t is the real wage. Note that equation (20) can be used in equation (19) to yield:

$$R_{kk'} = (1 - \alpha) \left(\frac{1 + x_{k'}}{i_k + x_{k'}} \right) \tag{21}$$

Critically, the implication of the above expression is that interest rates are independent of technology shocks.

4.1 Response to shocks

This section includes the responses of R_t, N_t, P_t, Y_t,and w_t, to the monetary and technology shocks. Following Christiano, Eichenbaum, and Evans (1997), the response of variable $v_t =$

(N_t, Y_t, P_t, w_t) to a shock s_t is measured as an elasticity:

$$dv = \frac{\log\left(\frac{v_{t+1}}{v_t}\right)}{\log\left(\frac{s_t}{s_{t+1}}\right)}$$

where v_t is the value of the variable in state (s_{t-1}, s_t) and v_{t+1} is the realization in state (s_{t+1}, s_t). The response of the interest rate is in semi-elasticity form:

$$dR = \frac{R_{t+1} - R_t}{\log\left(\frac{s_t}{s_{t+1}}\right)}$$

Table 2 presents this characterization of equilibrium behavior.

Qualitatively, the responses to a monetary expansion in Table 2 match those found by Christiano, Eichenbaum, and Evans (1997). The elasticities are slightly weaker here, because of the absence of fixed costs and markups. The price and output elasticities sum to one due to velocity being constant; also, the response of labor and the real wage are the same because the labor supply elasticity, $\frac{1}{\psi}$, is set to unity.

The liquidity effect is clearly evident - for example, a monetary injection from the central bank increases in the supply of available funds to firms requiring a fall in the interest rate to clear the funds market. The resulting fall in labor costs causes an increase in labor hours and output. The increase in output is less than the increase in the money supply so prices increase as well.

The responses to a technology shock match what we expect: a positive shock increases the demand for labor, boosting employment, output, and real wages. The responses of prices and output are again dictated by constant monetary velocity. Note that, as implied by equation (21), the interest rate is not affected by technology shocks; this is due to the fact that consumption is not present in the agent's marginal rate of substitution between consumption and leisure and the assumption of unitary elasticity of labor supply.

5 Monetary Policy Rules

5.1 Estimated Taylor Rules

While the behavior of the limited participation model reported in Table 2 is a useful characterization of its equilibrium properties, our interest lies in those properties captured by the Taylor rule. To explore this further, it is necessary to specify and estimate the coefficients of a Taylor rule from the data. Specifically, we use the following specification for the Taylor rule:

$$R_t = \alpha + \beta \tilde{y}_t + \gamma \pi_t + \rho R_{t-1} \tag{22}$$

where $\tilde{y}_t$ is the output gap, π_t is the average inflation rate over the current and previous three quarters (calculated using the implicit price deflator for output), and R_t is identified as the Federal Funds rate. Taylor (1993) excluded the lagged interest rate term and recommended that β and γ be set equal to 0.5 and 1.5 in his original study. The subsequent literature has produced many variations on this theme such as using lagged values for output and inflation (Christiano and Gust (1999)), the expected inflation rate (Clarida, et al (1998, 2000)), and including lagged interest rates in order to capture interest rate smoothing. For our analysis, we use a simple form of the rule (including the lagged interest rate) and estimate the parameters using data from the sample period. We include the lagged interest rate for two reasons. First, the inclusion of lagged interest rates captures central bank interest-rate smoothing evident from strong positive autocorrelation in the money market rate. Also, including this term improves both the econometric fit and properties of the residuals.[7]

A critical step in estimating equation (22) is measuring the output gap, defined as the

[7] Exclusion of the lagged interest rate term induces serially correlated errors.

percentage deviation of output from its potential or trend value.[8] We use four different definitions of this measure: log-linear detrending, log-linear detrending using recursive least squares (or recursive residuals), Congressional Budget Office (CBO) estimates, and real-time estimates.

The traditional method of estimating the output gap assumes that the log of output follows a linear or quadratic trend. The difficulty with this definition is that future information about the path of output, not available to policymakers, is used to predict the Federal Funds rate in any given period. If the Taylor rule does in fact model monetary policy, using future information could bias the coefficient on the output gap. Alternatively, one could maintain the assumption of a linear trend while using a recursive estimation procedure to ensure that only information available up to time t is used in estimating potential output. The (recursive) residuals from this regression measure the output gap each period.

The CBO's structural estimate of quarterly potential GDP avoids these problems. The CBO estimates potential output using a structural model of the economy with current and lagged variables as inputs (Congressional Budget Office (1995). We define the output gap as percentage deviations of GDP from the CBO potential GDP series.

The CBO estimates are, however, subject to historical revision implying that the published data are not consistent with the information available to policymakers. To avoid this source of error in measuring the output gap, Orphanides, et. al. (2000) and Orphanides and

[8] As stressed by Orphanides (2001), another complication is the difference between published and real-time data, i.e. the data available to policymakers at the time of policy decisions. While we note that real-time estimates of both inflation and the output gap should be used, we focus entirely on measures of the output gap. In part, our decision to use the published series for inflation is based upon the result that using lagged values for this series does not significantly affect the parameter estimates (see Rudebusch and Svensson (1999) and McCallum and Nelson (1999)).

Norden (1999) use vintage data to measure errors in estimating the output gap. Orphanides and Norden (1999) show that problems associated with measuring the output gap derive mainly from poor real-time estimates rather than revisions in published historical data. As shown below, our results are consistent with this finding.

To address this issue, we estimate the output gap using real-time data, presented in the fourth panel of each table. We extend the Croushore and Stark (2001) data set to include the 1959:3-1965:4 using information published in the *Survey of Current Business*.[9] The real-time data set reports published quarterly statistics available at the beginning of each quarter (or each month). We estimate the output gap by fitting GDP to a log-linear trend to the real GDP series available each quarter, 1959:3-1998:3. The real-time estimates are subject to neither historical revision nor the problem of using future information to estimate potential output.

5.2 Results

Tables 3 presents the coefficient estimates over the sample period 1959:3-1998:4. The estimated coefficients are similar for three of the four methods used to identify the output gap. The traditional method of estimating the output gap, linear detrending, differs significantly from the rest of the estimates. We take this results as being suggestive that using future information to estimate potential output results in a poor measure of the output gap relevant to policymakers. Also, this suggests that historical revisions do not significantly affect Taylor-rule estimates. The important feature to note, however, is that, regardless of

[9] The Croushore and Stark (2001) data set reports statistics available on a monthly or quarterly basis. We use data for real GDP reported in February, May, August, and November from November 1965-February 1999. We then fit a log-linear trend to real GDP for each available data set to derive the most recent estimate of the output gap.

the definition of the output gap, the coefficients on both inflation and the output gap are positive.

5.3 Taylor Rule in the Limited Participation Model

The Taylor rule coefficients implied by the limited participation model are next computed using the moments of the equilibrium unconditional distribution of the model.[10] The coefficients from two versions of the rule (differentiated by whether or not the lagged interest rate is included) are presented in Table 4. The important result is that the model is incapable of producing Taylor rule coefficients similar to that observed in the data. While the coefficient on inflation has the correct sign, it is much smaller than that estimated from the data. Even more problematic is that the model produces a negative coefficient on output. This is due to two factors: the liquidity effect and that fact that technology shocks do not affect interest rates. Hence, in equilibrium the correlation between interest rates and output are necessarily negative.

6 Conclusion

Monetary theory provides the link between output, inflation, nominal interest rates and monetary aggregates. While the relationship between the first three variables has received considerable scrutiny in the last decade, the behavior of monetary aggregates has been given

[10] We compute the coefficients using the following system of equations:

$$\begin{aligned} cov(R_t, y_t) &= \beta var(y_t) + \gamma cov(y_t, \pi_t) + \rho cov(y_t, R_{t-1}) \\ cov(R_t, \pi_t) &= \beta cov(\pi_t, y_t) + \gamma var(\pi_t) + \rho cov(\pi_t, R_{t-1}) \\ cov(R_t, R_{t-1}) &= \beta cov(R_{t-1}, y_t) + \gamma cov(R_{t-1}, \pi_t) + \rho var(R_{t-1}) \end{aligned}$$

where the variables are in deviation form. This is equivalent to the system of equations used to derive least squares estimates. Output in the model is equivalent to the output gap in the data because output is stationary in the model.

short shrift. We think this exclusion is a mistake since it ignores a critical dimension of monetary models, namely, money demand. Our analysis of this dimension illustrates that the liquidity factor present in the limited participation model produces a Taylor rule unlike that seen in the data.

7 Appendices

7.1 Appendix 1 - Parametrization of the Markov process

Using the method described in the paper, the following Markov process for the money and technology shocks is estimated from the data:

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ z_1 \\ z_2 \end{pmatrix} = \begin{pmatrix} 0.0069 \\ 0.0161 \\ 0.0235 \\ 0.9728 \\ 1.0149 \end{pmatrix} \qquad \Pi = \begin{pmatrix} 0.7222 & 0.1667 & 0.0000 & 0.05555 & 0.05555 & 0.0000 \\ 0.0882 & 0.6471 & 0.1471 & 0.0000 & 0.0588 & 0.0588 \\ 0.0526 & 0.2632 & 0.5790 & 0.0000 & 0.0526 & 0.0526 \\ 0.0000 & 0.0476 & 0.0000 & 0.5238 & 0.3810 & 0.0476 \\ 0.0000 & 0.0256 & 0.0256 & 0.2308 & 0.4872 & 0.2308 \\ 0.0000 & 0.0769 & 0.0769 & 0.0000 & 0.3077 & 0.5385 \end{pmatrix}$$

$$P = (0.0904, 0.2112, 0.1229, 0.1351, 0.2570, 0.1834)$$

The $x_j$and z_j denote the conditional mean for monetary base growth and technology shocks in state j while Π and P are the transition probability matrix and vector of unconditional probabilities, respectively.

7.2 Appendix 2 - Data

The following series were obtained from the US-ECON data set provided by Haver Analytics.

1. GDPH - Gross domestic product (seasonally adjusted at annual rates, billions of chain-weighted 1992 dollars)

2. FNH - Fixed, non-residential investment (seasonally adjusted at annual rates, billions of chain-weighted 1992 dollars)

3. LHTNAGRA - Aggregate hours, wage & salary workers on non-agricultural payrolls (seasonally adjusted at annual rates, millions of hours)

4. LNT20N - Civilian noninstitutional population, both sexes, 20 years and over (thousands, non-seasonally adjusted)

5. FARAM - Monetary base, adjusted for changes in reserve requirements (seasonally adjusted, millions of dollars)

6. DGDP - Implicit price deflator, gross domestic product (seasonally adjusted)

7. FFED - Federal Funds rate (effective)

8. GDPPOTHQ - Real potential gross domestic product {CBO} (billions of chain-weighted 1992 dollars)

In addition, we used the real output series (ROUTPUT), available from November 1965-February 1999, from the Croushore and Stark (2001) real-time data set. To extend the data series for our sample, we used the real output series reported in the publication *BEA's Survey of Current Business*

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Table 1: Moments from Parameterized Markov Process

	MODEL 1		DATA	
	Monetary Shocks	*Technology Shocks*	*Monetary Shocks*	*Technology Shocks*
Mean	0.0161	0.0011	0.0160	0.0000
Std. Deviation	0.0053	0.0135	0.0068	0.0178
Corr(y_t,y_{t+1})	0.5227	0.8058	0.7184	0.9141
Corr(x_t,w_t)	-0.0198	-0.0198	0.1778	0.1778

Table 2: Responses to Monetary and Technology Shocks

	Monetary Policy Shock				
value of other shock*					
	dR	*dN*	*dP*	*dY*	*dw*
z_1	-0.5998	0.4335	0.7225	0.2775	0.4335
z_2	-0.6099	0.4388	0.7192	0.2808	0.4388
	Technology Shock				
	dR	*dN*	*dP*	*dY*	*dw*
x_i	0.00	0.7353	-1.4706	1.4706	0.7353

** Indicates conditional value of other shock. The value of the money shock had no influence on effects of the technology shock*

Table 3: Estimated Taylor Rules

Congressional Budget Office estimates

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.1472	0.1792	0.8214	0.4127
FFED(-1)	0.9041	0.0341	26.4963	0.0000
YGAP	0.1453	0.0321	4.5201	0.0000
INFAVG	0.5498	0.1830	3.0038	0.0031

Log-linear trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.7245	0.2476	2.9266	0.0040
FFED(-1)	0.8728	0.0356	24.4846	0.0000
YGAP	0.0367	0.0142	2.5802	0.0108
INFAVG	0.1228	0.2316	0.5303	0.5967

Recursive residuals

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.3176	0.1832	1.7334	0.0851
FFED(-1)	0.9138	0.0354	25.7984	0.0000
YGAP	0.1192	0.0304	3.9186	0.0001
INFAVG	0.6020	0.1908	3.1549	0.0019

Real-time estimates

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.3389	0.1758	1.9278	0.0557
FFED(-1)	0.9057	0.0336	26.9335	0.0000
YGAP	0.1568	0.0302	5.1872	0.0000
INFAVG	0.7331	0.1874	3.9115	0.0001

Table 4: Implied Taylor Rule Coefficients

Output gap	-2.16915
Inflation	0.00012
Output gap	-2.16922
Inflation	-0.00012
Lagged Interest Rate	0.00006