E C O N O M I C S   B U L L E T I N

Taking the Monetary Implications of a Monetary Model Seriously

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Abstract

It has become common practice in applied monetary economics to posit an interest rate rule as a component of the economic environment. Since the general equilibrium setting imposes a money demand relationship, 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 in a limited participation model that permits both technology and money shocks. We model the money supply as an exogenous Markov process and calibrate 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 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.While this approach imposes a relationship between interest rates and money supply through household money demand, the implications of this relationship are rarely examined.[1]

A recent speech by Mervyn King (2007) highlights renewed interest in the role of monetary aggregates in anchoring inflation. In this research, we treat the money supply process as the exogenous policy instrument and examine the endogenous behavior of the implied interest rate rule. In doing so, we therefore analyze 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 for two reasons: (1) nominal interest rates are affected by both Fisherian and liquidity factors, and (2) the asymmetric impact of monetary policy 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. Also, Williamson (2006) demonstrates how limited participation models serve a useful paradigm for understanding the distributional effects of monetary policy.

Here, the empirical test consists of calibrating the parameters of a Markov process describing the evolution of money supply to the data and then examining whether the model produces an interest rate rule similar to those from earlier studies.[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 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.

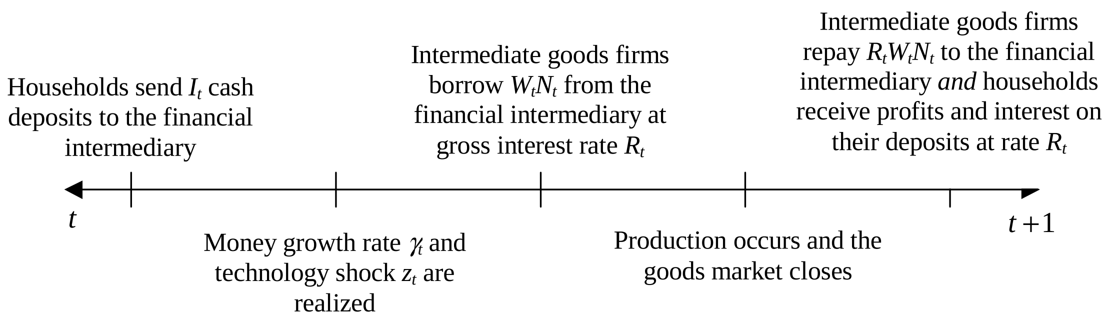
[1] There is a sizeable literature that does indeed take the monetary implications of monetary models seriously. Namely, literature in which the presence of a liquidity effect is examined. Examples are: Dow (1995) and Dotsey and Ireland (1995). Our analysis is closely related to this literature but differs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

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

2 Limited Participation Model with Technology Shocks

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 production is subject to stochastic shocks.[3] The timing of the model is given in Figure 1.

Figure 1: Timing of Markets in the Limited Participation Model



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.

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:

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

where $\beta \in (0,1)$. The utility function has the following form with $\psi_0, \psi > 0$:

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

[3]Christiano, Eichenbaum, and Evans (1997) include an intermediate goods sector, comprised of monopolistic competitors and a final goods sector to compare sticky-price and limited participation models.

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 current realizations of money and technology shocks are known. This decision consists of allocating M_t between nominal balances to be used for consumption, and deposits I_t to the banking sector. The gross nominal return on deposits 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 nominal balances allocated for consumption. This implies the following cash-in-advance constraint on consumption purchases:

$$P_t C_t \leq W_t N_t + M_t - I_t \tag{2}$$

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

$$M_{t+1} = W_t N_t + M_t - I_t - P_t C_t + r_t K_t + R_t \left(I_t + X_t\right) \tag{3}$$

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:

$$\frac{W_t}{P_t} = \psi_0 N_t^{\psi} \tag{4}$$

$$E_{t-1}\left[\frac{U_{c,t}}{P_t}\right] = E_{t-1}\left\{\beta R_t E_t\left[\frac{U_{c,t+1}}{P_{t+1}}\right]\right\} \tag{5}$$

Equation (4) 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 (5), 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, $Y_t = z_t K_t^{\alpha} N_t^{1-\alpha}$, 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. At the end of the period, these firms repay the wage bill, at gross interest rate R_t, after revenue from production is received, and the cost of capital to households.

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):

$$R_t \frac{W_t}{P_t} = (1-\alpha)\frac{z_t}{N_t^{\alpha}} \tag{6}$$

The labor supply and labor demand curves, i.e. equations (4) and (6) respectively, can be combined to yield the following expression characterizing equilibrium in the labor market:

$$R_t = \frac{(1-\alpha)}{\psi_0} z_t N_t^{-(\psi+\alpha)} \tag{7}$$

2.3 The Financial System

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:

$$W_t N_t = I_t + X_t \tag{8}$$

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(6) and the corresponding necessary condition for capital $\left(r_t = \alpha z_t N_t^{1-\alpha}\right)$ to yield:

$$F_D \equiv W_t N_t = \frac{(1-\alpha)}{\alpha}\frac{r_t}{R_t} \tag{9}$$

Equation (9) 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 (3).

The cash-in-advance constraint, equation (2), is assumed to be binding in all periods. Combining this condition with the equilibrium condition from the loan market equation (8) permits market clearing in the goods market to be expressed as:

$$P_t C_t = M_t + X_t \tag{10}$$

or, since $Y_t = C_t$ at equilibrium:

$$P_t = \frac{M_t + X_t}{Y_t} \tag{11}$$

Consequently, equilibrium velocity is always unity when defined in terms of the end-of-period money stock. Combining equations (7) and (11) yields the following expression:

$$\frac{W_t N_t}{P_t C_t} = \frac{I_t + X_t}{M_t + X_t} \tag{12}$$

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 (6) and the resource constraint, $C_t = z_t N_t^{1-\alpha}$, to rewrite the left-hand side of equation (12) to yield:

$$\frac{(1-\alpha)}{R_t} = \frac{I_t + X_t}{M_t + X_t} \tag{13}$$

From this expression, we see that increased liquidity in the loan market (i.e. an increase in X_t) will cause interest rates to fall.[4]

The central bank provides money to the financial system:

$$x_t \equiv \frac{X_t}{M_t} = \frac{(M_{t+1} - M_t)}{M_t} \tag{14}$$

The money growth rate, x_t, follows a stationary Markov process described below.

3 Results

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 model parameters are calibrated based on observed money and technology shocks, 1964:1-2006:4. A complete description of the calibration exercise is given in the Appendix. 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.

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:

$$F_k = \beta E_k \left[\frac{R_{kk'} F_{k'}}{(1 + x_{k'})} \right] \tag{15}$$

[4] Note that, in equation (13) , both I_t and M_t are predetermined when the current value of X_t is realized.

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

$$F_k \equiv E_k \left[\frac{1}{(1 + x_{k'}) - \left(\frac{i_k + x_{k'}}{1+\psi} \right)} \right] \tag{16}$$

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

$$R_{kk'} = \frac{(1-\alpha)}{\psi_o} z_{k'} N_{kk'}^{-(\alpha+\psi)} \tag{17}$$

Finally, the ratio of funds in the goods and lending markets (equation (12)) yields an additional 36 equations which can be written as:

$$\psi_0 N_{kk'}^{\alpha+\psi} = z_{k'} \left(\frac{i_k + x_{k'}}{1 + x_{k'}} \right) \tag{18}$$

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 (18) can be used in equation (17) to yield:

$$R_{kk'} = (1-\alpha) \left(\frac{1 + x_{k'}}{i_k + x_{k'}} \right) \tag{19}$$

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

3.1 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 decline 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 (19), 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.

3.2 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. [5] The important result is that the model is incapable of producing Taylor rule responses similar to those from Taylor (1993), Clarida, Gali, and Gertler (1998, 2002), and others. While the coefficient on inflation has the correct sign, it is much smaller than typical estimates in 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.

4 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 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.

[5] 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.The empirical output gap is equivalent to stationary output in the model.

5 Appendix: Calibration

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 1964:1 to 2006:4. 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 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. The capital stock was calculated using the perpetual inventory method, using data from 1947:1 to 2006:4. The investment series is seasonally-adjusted fixed private nonresidential investment and quarterly depreciation is assumed to be 2.0%. All variables are in per-capita terms. The 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:

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

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 $x_t \leq \bar{x} - \frac{\delta}{2}$.

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

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ z_1 \\ z_2 \end{pmatrix} = \begin{pmatrix} 0.0094 \\ 0.0170 \\ 0.0247 \\ 0.9828 \\ 1.0118 \end{pmatrix} \qquad \Pi = \begin{pmatrix} 0.0391 & 0.4348 & 0.0435 & 0.0435 & 0.0870 & 0.0000 \\ 0.2000 & 0.4000 & 0.2000 & 0.0000 & 0.1143 & 0.0857 \\ 0.0909 & 0.3182 & 0.4545 & 0.0000 & 0.0909 & 0.4545 \\ 0.0741 & 0.0370 & 0.0000 & 0.7037 & 0.1852 & 0.000 \\ 0.0513 & 0.0256 & 0.0000 & 0.1795 & 0.4872 & 0.2564 \\ 0.0000 & 0.0800 & 0.1600 & 0.0400 & 0.2800 & 0.4400 \end{pmatrix}$$

$$P = (0.1243, 0.1965, 0.1248, 0.1778, 0.2308, 0.1459)$$

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.

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Table 1: Moments from Parameterized Markov Process and Data

	Money Shocks, x_t		**Technology Shocks, z_t**	
	Data	Model	Data	Model
Mean	0.0168	0.0168	0.000	−0.0011
Std. Deviation	0.0068	0.0058	0.0128	0.0144
AR(1)	0.4832	0.5571	0.8782	0.5531
Corr. (x_t, z_t)	−0.0246	−0.0384		

Table 2: Responses to Monetary and Technology Shocks

			Monetary Shock		
State	dR	dN	dP	dY	dw
z_{low}	−0.648	0.459	0.707	0.459	0.707
z_{high}	−0.612	0.440	0.718	0.440	0.718

			Technology Shock		
State	dR	dN	dP	dY	dw
x_i	−0.000	0.735	−1.471	1.471	−1.471

Table 3: Implied Taylor Rule Coefficients

	Coefficient
Output gap	−2.18628
Inflation rate	−0.00013
Output gap	−2.18690
Inflation rate	−0.00011
Interest rate (lagged)	−0.00045