Inside Money, Outside Money and Short Term Interest Rates*

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Abstract

Different monetary aggregates covary very differently with short term nominal interest rates. Broad monetary aggregates like $M1$ and the monetary base covary positively with current and future values of short term interest rates. In contrast, the nonborrowed reserves of banks covary negatively with current and future interest rates. Observations like this 'sign switch' lie at the core of recent debates about the effects of monetary policy actions on short term interest rates. This paper develops a general equilibrium monetary business cycle model which is consistent with these facts. Our basic explanation of the 'sign switch' is that movements in nonborrowed reserves are dominated by exogenous shocks to monetary policy, while movements in the base and $M1$ are dominated by endogenous responses to non-policy shocks.

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1. Introduction

Different monetary aggregates covary very differently with short term nominal interest rates. Broad monetary aggregates like $M1$ and the monetary base covary positively with current and future values of short term interest rates. In contrast, the nonborrowed reserves of banks covary negatively with current and future interest rates. Observations like this 'sign switch' lie at the core of recent debates about the effects of monetary policy actions on short term interest rates.[1] This paper develops a general equilibrium monetary business cycle model which is consistent with these facts. Our basic explanation of the 'sign switch' is that movements in nonborrowed reserves are dominated by exogenous shocks to monetary policy, while movements in the base and $M1$ are dominated by endogenous responses to non-policy shocks.

To make this argument we require a model with the following features. First, it must allow for several types of shocks. This is a necessary condition for addressing the sign switch observations. Here, we take the simplest possible approach, by allowing for two shocks: exogenous shocks to the growth rate of the monetary base and exogenous shocks to technology. Second, the model must have elements which have the effect of endogenizing the broad monetary aggregates. In our setup, the most important element is a banking sector which produces loans and demand deposits. These respond positively to favorable technology shocks. Since these shocks also have the effect of raising equilibrium interest rates, the model can account for the observed positive correlation between $M1$ and interest rates. Third, to account for the positive relation between the monetary base and interest rates we take a particular stand on Federal reserve monetary policy. We assume that innovations to the growth rate of the monetary base are composed of two components, each of which is set by the monetary authority. (The composition of the base, between bank reserves and currency,

[1] Authors like Christiano and Eichenbaum (1992,1995), Eichenbaum (1991) and Strongin (1995) who have emphasized the behavior of nonborrowed reserves, claim to have found strong evidence of important liquidity effects, i.e., that one-time, positive policy shocks to the monetary base drive nominal interest rates down. Authors like Barro (1981), King (1991), Mishkin (1981) and Gordon and Leeper (1993) who have emphasized the behavior of monetary aggregates like the base and $M1$ claim that the evidence in favor of liquidity effects is weak or nonexistent.

is determined endogenously.) One component is purely exogenous, while the other reacts to contemporaneous innovations in technology. We identify the former with innovations to the nonborrowed component of the monetary base. We identify the latter, which is positively correlated with interest rates, with innovations in borrowed reserves. It is the reactive component of innovations to the monetary base that allows the model to account for the observed positive correlation between the base and the interest rate.[2]

Fourth, our model must incorporate elements which imply that nonborrowed reserves covary negatively with the interest rate. We accomplish this in part by including features in the model which ensure that exogenous policy shocks to the base generate important liquidity effects. The friction that accomplishes this in our model is the same as that underlying the limited participation assumption used in Lucas (1991), Fuerst (1992), Christiano (1991) and Christiano and Eichenbaum (1992,1995). This is the assumption that households do not adjust their currency holdings immediately in response to shocks in their environments. The papers just cited embed the limited participation assumption in cash-in-advance environments. In our model, agents can use demand deposits and credit, in addition to cash, to make consumption purchases. We adapt the limited participation assumption to this richer environment. When we do this, we find that a positive policy shock to the base drives interest rates down in the model.

The limited participation assumption, together with our specification of monetary policy, guarantees that innovations to nonborrowed reserves coincide exactly with innovations to the exogenous component of monetary policy. Given our specification of policy, the only way this could fail to be true is if the limited participation assumption did not hold and currency holdings could contemporaneously respond to shocks. For example, a positive innovation to technology could in principle trigger a positive innovation in nonborrowed reserves if it generated a contemporaneous fall in currency holdings. Similarly, an exogenous $1 increase in the monetary base could generate less than a $1 increase in nonborrowed reserves if it

[2]Movements in the nonborrowed component of the monetary base (i.e., currency plus nonborrowed reserves) are implemented by the actions of the Federal Reserve Open Market committee. The movements in reserves are 'nonborrowed' because they are effected by a swap of ownership over assets: reserves at the central bank in exchange for interest bearing assets, typically U.S. government debt. Movements in borrowed reserves occur with variations in the amount of loans made by at the Federal Reserve discount window. Our model of the actions of these two organs of the Fed abstracts from the details of how they implement policy, and simply assumes that they effect changes in reserves by 'helicopter drop'.

triggered a contemporaneous rise in currency. But, the limited participation assumption rules out contemporaneous responses of currency to shocks.

Though innovations to nonborrowed reserves reflect only exogenous policy shocks to the base, nonborrowed reserves are nevertheless endogenous in our model because they respond to all shocks with a delay. Still, our assumptions are enough to guarantee that movements in nonborrowed reserves are quantitatively dominated by exogenous monetary policy shocks. We presume that our basic results would also obtain if innovations to the nonborrowed component of the base contained a contemporaneous reactive component.

In sum, our model accounts for the positive comovements between the base, $M1$ and the interest rate as reflecting the importance of shocks to the demand for money (stemming, in our analysis, from technology shocks), the ability of the banking system to produce inside money, and the nature of monetary policy. It accounts for the negative comovements between nonborrowed reserves and the interest rate as reflecting the importance of liquidity effects in the monetary transmission mechanism.

The remainder of this paper is organized as follows. In section 2 we summarize some key facts regarding the dynamic co-movements between different monetary aggregates, output and the federal funds rate. Section 3 presents the model. Section 4 reports its quantitative properties. Finally, section 5 contains some concluding remarks.

2. Some Basic Facts

In this section we briefly summarize some basic facts about the dynamic comovements between the federal funds rate, real GNP and different monetary aggregates. These facts motivate the model of section 3 by documenting the sign switch' and lead - lag relationships between money and output discussed in the introduction.

We consider three monetary aggregates: non borrowed reserves, NBR (CITIBASE mnemonic FMRNBC), the base, $M0$ (FMBASE), and $M1$ (FM1). In addition we use data on the federal funds rate, FF (FYFF) and real GDP, Y,(GDP). The (quarterly) time series on all these variables display pronounced trends over the sample period 1959:1 - 1992:4. Consequently, some stationarity-inducing transformation of the data must be adopted. Here we work with the filter developed by Hodrick and Prescott (1980). Specifically, all of the statistics discussed in this section pertain to variables which have been logged and processed via the Hodrick and Prescott (HP) filter.

Figure 1 presents our point estimates of $\rho(FF_t, NBR_{t-\tau})$, $\rho(FF_t, M0_{t-\tau})$ and $\rho(FF_t, M1_{t-\tau})$, $\tau = -6, ..., 6$, where ρ denotes the correlation operator. The solid lines in Figure 1 denote point estimates of the correlations while the dashed lines correspond to a one standard deviation band about the point estimates.

Consider first the results for nonborrowed reserves. Notice that there is a strong, statistically significant negative contemporaneous correlation ($-.54$) between FF_t and NBR_t. Also note that FF_t is negatively correlated with leads and lags of NBR_t up to one year.[3] The key thing to notice about the correlations involving $M0$ and $M1$ is how different they are from those involving nonborrowed reserves. In particular, neither $M0$ nor $M1$ displays a significant contemporaneous correlation with FF_t. Moreover both are positively correlated with future values of FF_t but negatively correlated with lagged values of FF_t. Interestingly, the only significant difference between the correlations involving $M0$ and $M1$ is that the latter are estimated much more precisely. In any event, it is clear that nonborrowed reserves

[3]Christiano and Eichenbaum (1992) document the robustness of these conclusions to different sample periods and different transformations of the data.

covary quite differently with the federal funds rate than does M1. The term 'sign switch' is a short hand way of summarizing the main difference: nonborrowed reserves are negatively correlated with current and future values of the federal funds rate while the opposite is true for $M0$ and $M1$. Based on these correlations, it is perhaps not surprising that analysts working with $M0$ and $M1$ conclude that innovations in these monetary aggregates lead to a rise in interest rates while analysts working with NBR conclude the opposite.

Figure 2 presents our point estimates of $\rho(NBR_t, Y_{t-\tau})$, $\rho(M0_t, Y_{t-\tau})$ and $\rho(M1_t, Y_{t-\tau})$, $\tau = -6, ..., 6$. Notice that both $M0$ and $M1$ display a strong positive correlation with real GDP (0.34 and 0.29, respectively). In contrast, NBR is negatively correlated with current real GDP ($\rho(NBR_t, Y_t) = -0.22$). Nevertheless all three monetary aggregates lead real GDP in that they are positively correlated with future values of Y_t . This basic fact (at least regarding $M0$ and $M1$) has been stressed by a variety of authors. Friedman and Schwartz (1964), among others, cite it as evidence that monetary policy has been an important source of aggregate output fluctuations. King and Plosser (1984) argue that the key to interpreting this fact lies in the endogeneity of money. Sources of endogeneity in broad monetary aggregates like $M1$ include the response of the banking system and the Federal Reserve's discount window to shifts in the demand for money, say because of technology shocks. The model of section 3 allows for both endogenous and exogenous sources of positive comovements between monetary aggregates and output.

Finally Figure 3 presents our point estimates of $\rho(FF_t, Y_{t-\tau})$, and $\rho(FF_t, \Delta Y_{t-\tau})$, $\tau = -6, ..., 6$. Here Δ denotes the first difference operator. Notice that FF_t is positively correlated with Y_t but negatively correlated with future values of Y_t. This is consistent with the well-known observation that interest rates tend to be at their highest level at the peak of the business cycle. So a high level of the time t interest rate is associated with *lower* future values of real output. This is reflected in the fact that FF_t displays a sharp negative correlation with current and future growth rates of output (e.g. $\rho(FF_t, \Delta Y_t) = -.33$) and $\rho(FF_t, \Delta Y_{t+1}) = -.52$). In conjunction with the recent VAR literature aimed at studying the dynamic effects of exogenous shocks to monetary policy, these findings provide strong motivation for developing monetary business cycle models.[4] To us it seems unlikely that business cycle models - real or

[4]See Christiano, Eichenbaum and Evans (1994) and the references therein.

monetized - which do not take asset markets frictions seriously - will be able to convincingly account for the fact that high interest rates are a signal of lower future output.

We conclude this section by summarizing the key features of the data that we wish to account for. To summarize, there are three key facts that a reasonable monetary business cycle model ought to be consistent with. First, different monetary aggregates covary differently with interest rates and output. Simple monetized business cycle models which do not distinguish between different concepts of money cannot hope to account for these features of the data. Moreover, attempts to evaluate those models are inevitably forced to arbitrarily focus on one or another of the competing monetary aggregates. To us, this serves as strong motivation for developing models with multiple monetary aggregates.Second, high nominal interest rates forecast downturns in output. Third, broad monetary aggregates are positively correlated with output.

3. The Model

We consider a two sector economy that is populated by a large number of infinitely lived households. The first sector produces a good that can be consumed or invested as capital. The second sector consists of banks who produce demand deposits for households and make loans for working capital and investment purchases. Households supply labor and capital to both sectors. In addition they purchase consumption goods using a stochastic 'shopping technology' that allows households to economize on shopping time by use of currency and demand deposits. Analogous to existing limited participation models, we assume that, each period, households allocate their nominal assets between currency and interest bearing deposits at banks. These deposits along with deposits arising from cash injections by the monetary authority constitute the reserves of the banking sector.

The Goods Producing Firm: Technology and Choice Problem

The technology for producing new goods is given by:

$$y_t = f(k_{ft}, l_{ft}, n_{ft}, x_{ft}, z_t) = a_f x_{ft} l_{ft} k_{ft}^{\alpha} (z_t n_{ft})^{1-\alpha} \tag{3.1}$$

Here a_f is a positive scalar, $0 < \alpha < 1$ while k_{ft}, n_{ft}, and l_{ft} denote time t units of capital, number of persons working, and the length of the workweek in the goods producing sector, respectively. The economy wide technology parameter z_t evolves according to

$$z_t = \exp(\mu_z t) \tag{3.2}$$

where $\mu_z > 0$. The variable x_{ft} evolves according to

$$x_{ft} = x_{ft-1}^{\rho_f} \exp(\epsilon_{ft}). \tag{3.3}$$

Here ϵ_{ft} is a mean zero, iid shock to the production technology which has standard deviation σ_f. Output of this sector can either be consumed or invested to augment the capital stock.

According to (3.1), output is linear in the workweek. This reflects our assumption that the flow of services from capital and from persons employed is proportional to the length of the workweek. So according to (3.1), doubling the length of the workweek is equivalent to doubling the flow of services from capital and persons employed. This technology is the same as that used in Kydland and Prescott (1992) and Hornstein and Prescott (1993) among others.[5]

Perfectly competitive firms produce output using this technology. By assumption all inputs (labor and capital services) must be paid in advance of production. These payments are financed by working capital loans obtained from banks. Loans are repaid at the end of the period after the consumption good market closes. We denote the net time t interest rate on these loans by r_{ft}. The price level and the rental rate on capital are given by P_t and r_{kt}, respectively. The firm maximizes time t profits:

$$P_t f(k_{ft}, l_{ft}, n_{ft}, z_t, x_{ft}) - (1 + r_{ft}) r_{kt} P_t K_{ft} - (1 + r_{ft}) W_t(l_{ft}) n_{ft} \tag{3.4}$$

by choice of k_{ft}, n_{ft} and l_{ft} subject to (3.1), (3.2) and (3.3). The wage function $W_t(l_{ft})$ gives the nominal wage that the firm must pay to a worker as a function of the length of the workweek. The firm is owned by the representative household which receives any profits at the of the period. However, given our assumptions, profits will be zero in equilibrium.

The first order conditions to the firm's problem are given by

$$f_{kt} = (1 + r_{ft}) r_{kt} \tag{3.5}$$

$$f_{nt} = (1 + r_{ft}) W_t(l_{ft}) / P_t. \tag{3.6}$$

and

$$f_{lt} = (1 + r_{ft}) W_t'(l_{ft}) n_{ft} / P_t. \tag{3.7}$$

Here $W_t'(l_{ft})$ denotes the derivative of $W_t(l_{ft})$ while f_{kt}, f_{nt} and f_{lt} denote the time t marginal products of capital, persons employed and the workweek in the goods producing sector,

[5]See Bresnahan and Ramey (1994) and Foss (1994) for industry level evidence regarding this type of technology.

respectively. Notice that firms equate the time marginal product of the different factors of production to their marginal costs, inclusive of financing costs for working capital loans.

Banking Firms: Technology and Choice Problem

The banking technology is used to produce demand deposits which are useful for making transactions. This technology is given by:

$$h(k_{bt}, l_{bt}, n_{bt}, e_t, x_{bt}, z_t) = a_b[l_{bt}k_{bt}^{\alpha}(z_t n_{bt})^{1-\alpha}]^{\xi} e_t^{1-\xi} \tag{3.8}$$

Here a_b is a positive scalar, $0 < \alpha < 1$ while k_{bt}, n_{bt}, and l_{bt} denote time t units of capital, number of persons working and the length of the workweek in the banking sector, respectively. The variable e_t denotes the real value of time t excess reserves.

This formalization of the 'banking' technology is consistent with Lucas (1993) who assumes that real resources are required to run the banking sector. In actuality, it is costly for banks to manage their assets and their liabilities. As in Lucas (1993), we choose in this paper to concentrate on the costs of managing the bank's major liability: demand deposits.

Notice that we have included excess, rather than total reserves, as inputs to the production process for demand deposits. This is because, from the perspective of the banking system, required reserves play no role in protecting the system from unusually large withdrawals of currency. Below we discuss the role of reserve requirements in determining total, required and excess reserves.

The banks' assets consist of cash reserves and loans. Cash reserves flow to the bank from two sources. At the beginning of the period, households deposit A_t dollars in the bank. In addition, during the period, the monetary authority debits or credits households' checking accounts with X_t dollars. Consequently, total time t cash reserves of the banking system equal $A_t + X_t$. At the end of this section we discuss the law of motion for X_t.

Banks use cash reserves to make loans to finance working capital as well new investment purchases. Let S_t denote the bank's time t loans:

$$S_t = W_t(l_{ft})n_{ft} + W_t(l_{bt})n_{bt} + r_{kt}P_tK_t + P_tI_t/(1 + r_{at}) \tag{3.9}$$

where K_t equals K_{ft} plus K_{bt}. The total time t assets of the banking system are equal to its reserves plus outstanding loans: $A_t + X_t + S_t$.

The mechanics of a bank loan work as follows. When a bank makes a loan, it sets up a checking account for the amount of the loan. So the time t liabilities of the banking system equal total demand deposits, D_t: the sum of the households' and firms' checking accounts Since total liabilities equal total assets, we have that

$$D_t = A_t + X_t + S_t. \tag{3.10}$$

The monetary authority imposes a reserve requirement that banks must hold at least a fraction τ of their demand deposits in the form of currency. Consequently, nominal excess reserves, E_t, are given by

$$E_t = A_t + X_t - \tau D_t. \tag{3.11}$$

Consider now the choice problem of the banking firm. The time t interest rate on a bank loan, which is repaid at the end of the period, is given by r_{ft}. The interest rate which banks pay households on demand deposits, $\widehat{r}_t^a$, is determined at the beginning of the period prior to the realization of the time t shocks. Banks borrow and lend reserves in an inter bank spot market after the realization of the monetary policy shock. Let $r_{at}(\omega_t)$ denote the time t interest rate on inter bank loans in the spot market. Here ω_t denotes the time t state of the world.

To develop the relationship between $\widehat{r}_{at}$ and $r_{at}(\omega_t)$, we let $q_t(\omega_t)$ denote the beginning of time t forward price of a unit of reserves to be delivered at the end of time t, in state ω_t. We normalize these forward prices so that $\sum_{\omega_t} q_t(\omega_t)$ is equal to one. The interpretation is that a promise to purchase one unit of reserves at time t, state ω_t costs $q_t(\omega_t)$ units of reserves at the beginning of the period.

Profit maximization by banks implies that

$$\widehat{r}_t^a = \int_{\omega_t} q_t(\omega_t) r_{at}(\omega_t). \tag{3.12}$$

In what follows we suppress the explicit dependence of r_{at} on ω_t. Below we discuss the determination of the forward prices.

Total interest payments on demand deposits valued at spot prices are $r_{at}(S_t + A_t + X_t)$. Since operating costs are $(1 + r_{ft})r_{kt}P_tK_{bt} + W_t(l_{bt})(1 + r_{ft})n_{bt}$, the problem of the bank is to maximize time t profits

$$F_t = r_{ft}S_t - r_{at}(S_t + A_t + X_t) - (1 + r_{ft})r_{kt}P_tk_{bt} - W_t(l_{bt})(1 + r_{ft})n_{bt} \tag{3.13}$$

by choice of A_t, S_t, k_{bt}, l_{bt}, and n_{bt} subject to (3.8), (3.9), (3.10) and (3.11). The first order conditions to this problem are given by

$$(1 + r_{ft})r_{kt} = \frac{h_{kt}}{(1 + \tau h_{et})}(r_{ft} - r_{at}) \tag{3.14}$$

$$\frac{(1 + r_{ft})W_t(l_{bt})}{P_t} = \frac{h_{nt}}{(1 + \tau h_{et})}(r_{ft} - r_{at}) \tag{3.15}$$

$$\frac{(1 + r_{ft})W_t'(l_{bt})n_{bt}}{P_t} = \frac{h_{lt}}{(1 + \tau h_{et})}(r_{ft} - r_{at}) \tag{3.16}$$

$$r_{at} = \frac{h_{et}(1 - \tau) + 1}{(1 + \tau h_{et})}(r_{ft} - r_{at}). \tag{3.17}$$

Here h_{kt}, h_{nt}, h_{lt}, and h_{et} denote the time t marginal products of capital, persons, workweek and excess reserves in producing demand deposits.

To provide intuition for these first order conditions, use (3.8), (3.9) and (3.10) to consolidate the constraints on the bank's problem as

$$\frac{A_t + X_t + S_t}{P_t} = h(k_{bt}, n_{bt}, l_{bt}, \frac{A_t + X_t - \tau(A_t + X_t + S_t)}{P_t}) \tag{3.18}$$

where we have suppressed the explicit dependence of the function h on shocks. Using the implicit function theorem we can express S_t via the function

$$S_t = P_t\hat{h}(k_{bt}, n_{bt}, l_{bt}, \frac{A_t + X_t}{P_t}; \tau). \tag{3.19}$$

Totally differentiating (3.18) we obtain

$$\frac{\partial S_t/\partial k_{bt}}{P_t} = \frac{h_{kt}}{(1 + \tau h_{et})},$$

$$\frac{\partial S_t/\partial n_{bt}}{P_t} = \frac{h_{nt}}{(1+\tau h_{et})}$$

$$\frac{\partial S_t/\partial l_{bt}}{P_t} = \frac{h_{lt}}{(1+\tau h_{et})} \qquad \text{and}$$

$$\partial S_t/\partial A_t = \frac{(1-\tau)h_{et}+1}{1+\tau h_{et}}.$$

Abstracting from reserve requirements, if the bank has one more unit of capital it can increase total real loans by h_{kt} (the marginal product of capital in loan production). But with reserve requirements, when a bank increases loans by \$1, its required reserves rise by $\$\tau$ so that excess reserves falls by $\$\tau$. Because excess reserves are productive, other things equal, total loans must (because of the production technology) fall by τh_{et}. When capital is used to create a loan this effect must be taken into account, so that the net increase in securities, $\frac{\partial S_t/\partial K_{bt}}{P_t}$, equals $\frac{h_{kt}}{(1+\tau h_{et})}$. The Euler equation for capital (3.14) equates the marginal cost of an extra unit of capital (r_{kt}) to the marginal revenue generated by the extra unit of capital, $\frac{\partial S_t/\partial Kb_t}{P_t} r_{ft}$. Similar intuition applies to the Euler equation for l_{bt} and n_{bt}.. Finally consider the expression $\partial S_t/\partial A_t$. A dollar increase in cash obtained via a unit increase in A_t generates a demand deposit liability of \$1 and a net increase in excess reserves of $\$(1-\tau)$. Given our technology, this allows total demand deposits to increase by $\$(1-\tau)h_{et}$. Since the initial increase in cash generated a demand deposit liability of \$1, total loans can increase by $\$(1-\tau)h_{et}+1$. Recall though that for every dollar increase in loans, required reserves rise by $\$\tau$ so that excess reserves fall by $\$\tau$. Taking this effect into account, the total increase in loans generated by an initial increase in A_t, $\partial S_t/\partial A_t$ equals $\frac{(1-\tau)h_{et}+1}{1+\tau h_{et}}$. The Euler equation for A_t, (3.17), equates, r_{at} (marginal cost of an extra unit of A_t) to $\frac{\partial S_t/\partial A_t}{P_t} r_{ft}$ (the marginal revenue generated by the extra unit of cash).

It is worth pointing out that the capital labor ratio in banking, k_{bt}/n_{bt} equals the capital labor ratio in goods production, k_{ft}/n_{ft} and that the work week in both week in both sectors is equal. This result follows by comparing the first order conditions for profit maximization in the two sectors. Specifically, dividing (3.14) by (3.15) and (3.15) by (3.16) we obtain an equation that equates the capital labor ratio with the ratio of the wage rate to the rental rate. In addition we obtain an equation that relates the workweek and the capital labor

ratio to the ratio of the $W'(l_{ft})$. Performing similar operation on the goods producing firm's first order conditions, it is easy to see that we obtain equations identical to those which we just obtained for the bank. The result follows.

The Household

The representative household ranks alternative streams of consumption and leisure using the criterion function

$$E_0\{\sum_{t=0}^{\infty}\beta^t[n_tU(C_t^e, L_t^e) + (1-n_t)U(C_t^u, L_t^u)\}. \tag{3.20}$$

Here n_t is the probability of being employed, C_t^e denotes time t consumption if employed, L_t^e denotes time t leisure if employed, C_t^u denotes time t consumption if unemployed, L_t^u denotes time leisure if unemployed, and E_0 denotes the expectations operator conditional on the household's information set at the beginning of time 0. Below we discuss agents' information sets in greater detail. We assume that the period utility function is given by

$$U(C, L) = (CL^{\gamma})^{\psi}/\psi. \tag{3.21}$$

We normalize the household's time endowment to be 1. The household divides its time endowment into leisure, hours worked in the market place, l_{1t}, if a job is found, time spent acquiring consumption goods, l_{2t}, and time spent searching for employment, l_{3t}.

The technology involving l_{2t} is motivated by ideas in McCallum and Goodfriend (1987) and Lucas (1993). In particular, we suppose that households use currency, demand deposits and time to purchase consumption goods. The amount of time used, l_{2t}, is an increasing function of C_t, and a decreasing function of both real currency, M_t/P_t, and real demand deposits D_t/P_t. Here M_t and D_t denote the time t nominal values of currency and demand deposits, respectively, while P_t denotes the dollar price of one unit of the consumption good. The transactions technology is given by

$$l_{2t} = J\left[\left(\frac{P_tC_t}{M_t}\right)^{\theta}\left(\frac{P_tC_t}{D_t}\right)^{1-\theta}\right]. \tag{3.22}$$

Here J and θ are nonnegative scalars.

The search technology, is given by,

$$l_{3t} = \nu_0 n_t^{\nu_1}. \tag{3.23}$$

where ν_0 and ν_1 are nonnegative scalars. The basic idea here is that spending more time on search raises the probability of finding employment.

We now consider the choice problem of the representative household. In our quantitative work we assume that there are adjustment costs associated with changing portfolios between periods. For expositional reasons, we suppress these adjustment costs for now. This allows us to display the basic intuition underlying the household's Euler equation in a way that preserves on notation. In the next subsection we explicitly describe the adjustment cost technology.

We assume that there are perfect markets to insure households against the idiosyncratic risk of finding a job. In addition we assume that the time devoted by the household to finding a job, l_{3t}, is observable. This implies that households receive labor income $W(l_t)n_t$ if they choose a workweek of length of l_t and a probability of finding a job n_t. Notice that with specifications, households which are identical ex ante in their labor market decisions, receive the same income regardless of whether they are successful in finding a job.

Total household demand deposits are given by

$$D_{ht} = A_t + X_t + W(l_{1t})n_t + r_{kt}P_tK_t. \tag{3.24}$$

According to relation (3.24), households' demand deposits consist of cash that households deposit at the bank at the beginning of the period plus wage income and the rental income from capital, which are assumed to be directly deposited into households' checking accounts.

The households flow budget equation is given by

$$P_tC_t + Q_{t+1} + \frac{1 + r_{ft}}{1 + r_{at}} P_tI_t \leq D_{ht}(1 + \hat{r}_t^a) + M_t + F_t, \tag{3.25}$$

Here F_t denotes lump sum dividends equal to the time t profits of the representative banking firm. The variable Q_t denotes beginning of period t nominal assets. These must be allocated between currency, M_t, and demand deposits, A_t :

$$Q_t = M_t + A_t \tag{3.26}$$

Relation (3.26) indicates that the cost of investment is $\frac{1+r_{ft}}{1+r_{at}}$. This reflects two assumptions. First, investments must be financed with borrowed funds. Second, the demand deposits that are created when banks issue investment loans pay interest at the rate r_{at}. This implies that for each dollar that the household wishes to invest at the end of the period, it needs to borrow $(1+r_{at})^{-1}$ dollars at the beginning of the period. Since the interest rate on these loans is r_{ft} the cost of a one dollar investment is $\frac{1+r_{ft}}{1+r_{at}}$.The assumption that banks pay interest at rate r_{at} rather than $\widehat{r}_{at}$ on demand deposits created from investment loans is supposed to capture the notion that in reality investment activities are carried out by specialized firms on behalf of households. These firms are in closer contact with capital markets than households are on a day to day basis and earn an interest more analogous to r_{at} than $\widehat{r}_{at}$. We conjecture that our qualitative results would be the same if we assumed that the cost of investment equals $\frac{1+r_{ft}}{1+\widehat{r}_{at}}$.

Information Sets and the Household's Decisions

In order for the household's problem to be well defined, we need to be specify the information set that is available when various decisions are made. To this end, we let Ω_t denote the history of all shocks up to the end of time t, not including the time t realizations of idiosyncratic shocks indicating whether a given household has found employment. Let Ω_t^1 denote the union of Ω_t and the idiosyncratic employment shock.

The household's problem is to maximize (3.20) subject to (3.22) - (3.26) by choice of contingency plans for $\{C_t,\ Q_{t+1},\ K_{t+1},\ l_{1t},\ l_{2t}, l_{3t}, n_t,\ M_t,\ A_t\ :\ t \geq 0\}$. We assume that M_t and A_t are functions only of Ω_{t-1}^1, while the other variables are functions of Ω_t. The assumption that household consumption, investment and shopping time are independent of the realization of idiosyncratic employment uncertainty is motivated by a desire to minimize the complexity of the model.

The first order conditions for the household's problem are given by ,

$$E\left[(U_{ct} - \lambda_t P_t - v_t l_{2t}/C_t)\,|\Omega_t\right] = 0 \tag{3.27}$$

$$E\left[(-\lambda_t + \beta\mu_{t+1})\,|\Omega_t\right] = 0 \tag{3.28}$$

$$E\left[\left(-\lambda_t \frac{1+r_{ft}}{1+r_{at}} P_t + \beta\lambda_{t+1} P_{t+1}(r_{kt+1} + (1-\delta)\frac{1+r_{ft+1}}{1+r_{at+1}})\right)|\Omega_t\right] 0 \tag{3.29}$$

$$U_{l_1 t} + \lambda_t W_t'(l_{1t}) n_t + (1-\theta) v_t \frac{l_{2t} W_t'(l_{1t}) n_t}{(A_t + X_t + W_t(l_{1t}) n_t)} = 0 \tag{3.30}$$

$$U_{l_2 t} + v_t = 0 \tag{3.31}$$

$$U_{nt} + \lambda_t W_t(l_{1t}) + (1-\theta) v_t \frac{l_{2t} W_t(l_{1t})}{(A_t + X_t + W_t(l_{1t}) n_t)} = 0 \tag{3.32}$$

$$E\left[\left(\lambda_t - \mu_t + \theta v_t \frac{l_{2t}}{M_t}\right)|\Omega_{t-1}\right] = 0 \tag{3.33}$$

$$E\left[\left(\lambda_t(1+\hat{r}_{at}) - \mu_t + (1-\theta) v_t \frac{l_{2t}}{(A_t + X_t + W_t l_{1t})}\right)|\Omega_{t-1}\right] = 0 \tag{3.34}$$

Here v_t, μ_t,and λ_t are the Lagrange multipliers on (3.22), (3.26) and (3.25), respectively. In addition U_{ct} ,$U_{l_1 t}$, $U_{l_2 t}$ and U_{nt} denote the time t partial derivatives with respect to C_t, l_{1t}, l_{2t} and n_t.

It is convenient to define

$$\widetilde{U}_{ct} = U_{ct} + U_{l_2 t}\frac{l_{2t}}{C_t}.$$

This variable denotes the 'effective' marginal utility of consumption obtained after using the transaction technology function (3.22) to substitute for l_{2t} in the utility function. Eliminating the Lagrange multipliers we obtain the following Euler equations for k_{t+1}, l_{1t}, n_t, M_t and A_t :

$$E\left[\left(\frac{1+r_{ft}}{1+r_{at}}\widetilde{U}_{ct} - \beta\widetilde{U}_{ct+1}\left(r_{kt+1} + (1-\delta)\frac{1+r_{ft+1}}{1+r_{at+1}}\right)\right)|\Omega_t\right] = 0 \tag{3.35}$$

$$E\left[\left(\widetilde{U}_{ct} W_t'(l_{1t}) n_t / P_t - U_{l_2 t}\frac{(1-\theta) l_{2t}}{A_t + X_t + W_t(l_{1t}) l_{1t}} W_t'(l_{1t}) n_t + U_{l_1 t}\right)\Omega_t\right] = 0 \tag{3.36}$$

$$E\left[\left(\widetilde{U}_{ct} W_t(l_{1t}) / P_t - U_{l_2 t}\frac{(1-\theta) l_{2t}}{A_t + X_t + W_t(l_{1t}) l_{1t}} W_t(l_{1t}) + U_{nt}\right)\Omega_t\right] = 0 \tag{3.37}$$

$$E\left[\left(\widetilde{U}_{ct}/P_t - \beta\widetilde{U}_{ct+1}/P_{t+1} + \beta\theta U_{l2t+1}\frac{l_{2t+1}}{M_{t+1}}\right)|\Omega_{t-1}\right] = 0 \tag{3.38}$$

$$E\left[\left(\hat{r}_{at}\widetilde{U}_{ct}/P_t + U_{l_2 t}\left[\frac{\theta l_{2t}}{M_t} - \frac{(1-\theta) l_{2t+1}}{A_t + X_t + W_t l_{1t}}\right]\right)\Omega_{t-1}\right] = 0 \tag{3.39}$$

To understand (3.35), suppose that the household wishes to increase K_{t+1} by one unit. The first term on the left hand side of (3.35) is the time t effective utility cost associated with this action. The net return (which is stochastic) associated with the increase in K_{t+1} is r_{kt+1} $+(1-\delta)\frac{1+r_{ft+1}}{1+r_{at+1}}$. The second term on the left hand side of (3.35) gives the expected effective marginal utility benefits of these returns.

To understand (3.36), suppose that the household works one more unit of time in the market place and consumes the proceeds. There are two returns associated with this action. First, there is the effective utility gain in consumption, given by the first term on the left hand side of (3.36). Second, recall that wage payments are credited to household's checking accounts. Because of the assumed transactions technology, these payments reduce time spent transacting. The utility value of this reduction is given by the second term on the left hand side of (3.36). This action results in a loss in leisure, the utility value of which is given by the last term on the left hand side of (3.36). The intuition for (3.37) is similar to that underlying the (3.36).

To understand (3.38) suppose that the household spends one dollar less on time t consumption, increases its holding of M_{t+1} and then spends it on time t+1 consumption. The first term on the left hand side of (3.38) gives the time t effective utility loss associated with this action. The second term on the left hand side of (3.38) gives the effective utility gain associated with increasing consumption by $1/P_{t+1}$ units. The third term on the left hand side reflects the utility gain associated with the reduction in l_{2t+1} that occurs because M_{t+1} has been raised by one dollar.

To understand (3.39), suppose that the consumer reduces M_t by one unit, increases A_t and uses the proceeds to increase C_{t+1}. Given our transactions technology, the net effect on l_{2t} equals $\frac{\theta l_{2t}}{M_t} - \frac{(1-\theta)l_{2t}}{A_t+X_t+W_t l_{1t}}$. The utility value of this change in l_{2t} is given by the second term on the left hand side of (3.39). The net increase in Q_{t+1} due to the reallocation is $\hat{r}_{at}$. Viewed from the perspective of time t, the utility value of these extra dollars equals $\hat{r}_{at}$ $\beta E\left\{\tilde{U}_{ct+1}/P_{t+1} - \theta U_{l_2 t+1}\frac{l_{2t+1}}{M_{t+1}}|\Omega_{t-1}\right\}$. From (3.38), this equals the first term on the left hand side of (3.39).

We conclude this subsection by deriving the time t forward price, $q_t(\omega_t)$, of a dollar in state ω_t. We express this price in terms of beginning of period t dollars before ω_t is realized.

Our strategy is to describe an alternative interpretation of the model in which agents set contingency plans for all variables. The limited participation constraint takes the form of a restriction on the contingency plans for A_t and M_t. Specifically, we require that A_t and M_t be the same for all realizations of ω_t. Under these circumstances, the household's budget constraint can be expressed as

$$\int_{\omega_t} q_t(\omega_t)\left[P_t(\omega_t)C_t(\omega_t) + Q_{t+1}(\omega_t) + \frac{1+r_{ft}}{1+r_{at}}P_t(\omega_t)I_t(\omega_t)\right] \leq \tag{3.40}$$
$$\int_{\omega_t} q_t(\omega_t)\left[A_t + W(l_{1t}(\omega_t))n_t(\omega_t) + r_{kt}(\omega_t)P_t(\omega_t)K_t\right]$$

The first order condition with respect to consumption is now:

$$\beta^t U_{ct}(\omega_t) - \beta^t \lambda_0 q_t(\omega_t)P_t - \beta^t v_t(\omega_t)l_{2t}(\omega_t)/C_t(\omega_t) = 0 \tag{3.41}$$

where $\beta^t\lambda_0$ is the Lagrange multiplier on (3.40). Comparing (3.41) with (3.27) we see that $\lambda_0 q_t(\omega_t) = \lambda_t$ where λ_t is the Lagrange multiplier on (3.25). Since $\lambda_t = \widetilde{U}_{ct}$, $q_t(\omega_t)$ is proportional to $\widetilde{U}_{ct}$. It follows that

$$\widehat{r}_{at} = \frac{E[\widetilde{U}_{ct}(\omega_t)r_{at}(\omega_t)|\Omega_{t-1}]}{E[\widetilde{U}_{ct}(\omega_t)|\Omega_{t-1}]}$$

which gives a complete characterization of $\widehat{r}_{at}$.

Allowing for Adjustment Costs

The key friction embedded in our model is the limited participation assumption. We have formulated this friction by assuming that it is infinitely costly for households to adjust their portfolios within the period but costless to adjust portfolios between periods. Formulating the friction in this manner, has an important disadvantage. As in Lucas (1990), Fuerst (1992) and Christiano and Eichenbaum (1995), the liquidity effects associated with a monetary policy shock last only one period. To generate persistent liquidity effects, we extend our baseline specification and suppose that there are adjustment costs associated with changing household portfolios. In a precise sense to be defined below, *very small* adjustment costs render the model consistent with the notion that positive monetary policy shocks lead to *persistent* declines in short term interest rates.

We suppose that adjustment costs are denominated in units of labor, l_{4t}. Recall that the portfolio decision facing households is how to divide Q_t between M_t and A_t. We adopt the following adjustment cost technology which penalizes changes in M_t/M_{t-1}:

$$l_{4t} = \kappa(M_t, M_{t-1}) = \Lambda_1\{\exp[\Lambda_2(\frac{M_t}{M_{t-1}} - f)] + \exp[-\Lambda_2(\frac{M_t}{M_{t-1}} - f)] - 2\}. \tag{3.42}$$

Here Λ_1, Λ_2, and f are nonnegative constants. The parameter f is set so that level and marginal adjustment costs are zero in steady state.

The presence of adjustment costs requires that we change the Euler equations for M_t and A_t. Specifically, (3.38) and (3.39) are replaced by,

$$E\left[\begin{array}{c}\left(\widetilde{U}_{ct}/P_t - \beta\widetilde{U}_{ct+1}/P_{t+1} + \beta\theta U_{l2t+1}\frac{l_{2t+1}}{M_{t+1}}\right) \\ -\beta U_{l_{2t+1}}\kappa_1(M_{t+1}, M_t) + \beta^2 U_{l_2t+2}\kappa_2(M_{t+2}, M_{t+1})|\Omega_{t-1}\end{array}\right] = 0 \tag{3.43}$$

$$E\left[\left(\begin{array}{c}\widehat{r}_{at}\widetilde{U}_{ct}/P_t + U_{l_2t}\left[\frac{\theta l_{2t}}{M_t} - \frac{(1-\theta)l_{2t+1}}{A_t+X_t+W_t l_{1t}}\right] \\ -U_{l_2t}\kappa_1(M_t, M_{t-1}) + \beta U_{l_2t+1}\kappa_2(M_{t+1}, M_t)\end{array}\right)\Omega_{t-1}\right] = 0 \tag{3.44}$$

Here κ_1 and κ_2 denote the derivatives of the κ function with respect to its first and second arguments, respectively.

Equilibrium

Define the allocation functions $M_t(\Omega_{t-1})$, $A_t(\Omega_{t-1})$, $C_t(\Omega_t)$, $Q_{t+1}(\Omega_t)$, $K_{t+1}(\Omega_t)$, $l_{1t}(\Omega_t)$, $l_{2t}(\Omega_t)$, $l_{3t}(\Omega_t)$, $l_{4t}(\Omega_{t-1})$, $n_t(\Omega_t)$ and the price functions $\widehat{r}_{at}(\Omega_{t-1})$, $r_{kt}(\Omega_t)$, $r_{ft}(\Omega_t)$, $r_{at}(\Omega_t)$, $W_t(\Omega_t)$, $p_t(\Omega_t)$. Then,

a ***competitive equilibrium*** is a collection of allocation and price functions such that (i) the allocation functions solve the maximization problem of the household, the banking firm and the goods producing firm, and (ii) all markets clear. In the goods market this requires

$$C_t + K_{t+1} - (1-\delta)K_t = f(k_{ft}, l_{ft}, n_{ft}, z_t, x_{ft}) \tag{3.45}$$

Nonborrowed Reserves, Total Reserves, the Base, M1 and Monetary Policy

We conclude this section by (i) summarizing the monetary variables in our model, and their relationship to various monetary aggregates in the data, and (ii) discussing our assumptions about monetary policy.

The broadest monetary aggregate we consider is $M1_t$,which is defined as currency plus demand deposits. In our model $M1_t$ corresponds to $M_t + D_t$. The monetary base, $M0_t$, is defined as currency in the hands of the nonbanking public plus total bank reserves. In our model, total bank reserves equal $A_t + X_t$. So, $M0_t$ corresponds to $M_t + A_t + X_t$.

We now consider a variety of narrower monetary aggregates. Total bank reserves can be divided into required and excess reserves. In our model, these correspond to τD_t and E_t, respectively. Total bank reserves can also be divided into borrowed and non-borrowed components. To explain how we model these we discuss our assumptions about monetary policy.

We suppose that the base evolves according to

$$M0_{t+1} = (1 + x_t)M0_t, \tag{3.46}$$

where the net growth rate of the base, x_t, consists of two components:

$$x_t = x_{1t} + x_{2t}. \tag{3.47}$$

We assume that x_{1t} is purely exogenous, and evolves according to

$$x_{1t} = (1 - \rho_x)x + \rho_x x_{1t-1} + \epsilon_{x_1 t} \tag{3.48}$$

where x is a positive scalar, $|\rho_x| < 1$ and $\epsilon_{x_1 t}$ is a mean zero, iid shock which has standard deviation σ_{x_1}, and is uncorrelated with all other shocks in the model.

The second component of x_t, x_{2t}, is a function of the time t innovations to the economy. In our stochastic simulations, we allow only for two types of shocks, shocks to x_{1t}, and shocks to the goods production function, x_{ft}. We proceed under the assumption:

$$x_{2t} = b_1 \epsilon_{ft} + b_2 \frac{\epsilon_{ft}}{1 - \rho L}, \tag{3.49}$$

where b_1 and b_2 are scalars, $0 < \rho < 1$, and L is the lag operator. We interpret $x_{2t}M0_t$ as the change in the stock of borrowed reserves. The change in nonborrowed reserves equals the change in total reserves, less the change in borrowed reserves.

In (3.49) $b_1 + b_2$ represents the impact effect of a technology shock on borrowed reserves. We assume that this effect is positive, so that the specification parsimoniously captures the

notion emphasized by Goodfriend (1983) and others that the rationing rule used by the Fed at the discount window makes borrowed reserves an increasing function of shocks which raise short term interest rates.[6] We also assume $b_1 + b_2/(1-\rho) = 0$. This corresponds to the assumption that any funds injected at the discount window are ultimately withdrawn. This captures the notion that loans made at the window are transitory in nature, and must be repaid.

[6]Others who take this approach include Coleman, Gilles and Labadie (1994) and the references therein.

4. Quantitative Properties of the Model

4.1. Parameter Values

In this section we analyze the quantitative properties of our model. We begin by discussing the model parameter values. To date we have not formally estimated these parameters, but we plan to do so in the future.

The model has 25 parameters. The first 11, $(\alpha, A_f, \mu_z, \psi, \nu_0, \nu_1, \delta, \mu_x, \tau, \Lambda_1, \Lambda_2)$, were set as follows. The reserve requirement, τ, was set to 0.06, the sample average of the ratio of required reserves to $M1$ net of currency in the hands of the public. The production function parameter α was set to 0.36, a standard number in the real business cycle literature. The production parameter A_f was normalized to 1. The growth rate of productivity, μ_z,was set so as to imply an unconditional annual growth rate of output of 1.6%. This is the rate of growth of per capita output reported for the post-war period in Christiano and Eichenbaum (1992). The risk aversion parameter ψ was chosen to equal -0.5. The depreciation rate, δ, was set to imply an annual rate of depreciation of 8%, based on the investment and capital stock data analyzed in Christiano and Eichenbaum (1992). Finally, the money growth rate, x, was set so as to imply an unconditional annual rate of growth of 6.5% in the monetary base. This was chosen so that the model would imply an annual inflation rate of 4.8% in steady state, the post-war annual average. The parameters, Λ_1 and Λ_2 were set to 1 and 0.3, respectively, after experimenting with different values. The search technology parameter ν_1 was chosen to equal 3.4. This implies that a 1% increase in time devoted to search leads to a 0.3% increase in the probability of finding employment. To obtain a value for ν_0, we suppose that each unemployed person in the U.S. spends the same fraction of time, l_{1t}, as an employed person spends working. In addition, we make the simplifying assumption that employed people do not engage in search. Under these assumptions, the mean of l_{3t} is the product of the mean of the unemployment rate times the mean of the labor force participation rate times the mean value of l_{1t} :

$$l_3 = UR \times LFPR \times l_1$$

Based on post war average data, $l_3 = 0.015, UR = .066, LFPR = .6, l_1 = 0.38$.

The next 7 parameters, ($N, J, \theta, \gamma, A_h, \zeta, \psi$) were set so that, given the first 9 parameters just discussed, the steady state properties of the model are consistent with the following 7 steady-state statistics:

$$nl_1 = 0.23, r_f = 0.083, r_a = 0.069, \frac{D_t}{M_t} = 3.18, \frac{E_t}{P_t C_t} = 0.0004, \frac{D_t}{P_t C_t,} = 0.19, l_2 = .004.$$

Here, $1/N$ denotes the model period, expressed as a fraction of a year. The value of nl_1 is the sample average of the time series on per capita hours worked based on the data constructed by Hansen (1985) (see Christiano and Eichenbaum (1992).) This quantity is expressed as a fraction of the time endowment, which we assume equals 15 hours per day, per person. The values of r_f and r_a are the post-war sample averages of the prime lending rate and the federal funds rate, respectively (CITIBASE mnemonics FYPR and FYFF). The variables M_t, E_t, and D_t were measured using data on currency held by the non banking public, excess reserves held by the banking system and deposits held in US banks, respectively (CITIBASE mnemonics FMSCU, FMRRA - FMRQA and FM1-FMSCU). The variables P_t and C_t are the GDP deflator and the value of consumption used in Christiano and Eichenbaum (1992), respectively. The value of l_2 corresponds to 25 minutes per week, assuming a 15 hour per day time endowment. This value was selected *a priori*. All of the above quantities with a time dimension are expressed in annual rates. Prior to solving and simulating the model, parameters with a time dimension were converted to units corresponding to the time period of the model.

There remain the 7 parameters characterizing the stochastic properties of the shocks. The parameters ρ_f and ρ_x were set to 0.5 and 0.1. We set σ_f and σ_x to 0.0097 and 0.0038. Finally, we set the borrowed reserves parameters b_1, b_2, and ρ to 3, -2.1 and 0.3, respectively. These parameters were chosen by an informal search procedure that we view as a prelude to formal estimation. Our objective in this search was to identify a parameterization of the model which captures the facts emphasized in section 2 and which is consistent with the observed variability in aggregate output. All reported second moment properties of the model pertain to the model period.

Table 1 summarizes the model parameter values. The estimated value of N implies that the length of the model period is roughly one-half of the (quarterly) data sampling interval. To evaluate the plausibility of the other parameters, it is useful to look at their implications for the non stochastic steady state of the model. These are summarized in Table 2. A number of features are worth noting here. First, the fraction of the aggregate capital stock and aggregate employment used in the banking sector are very small. This reflects the large value of A_b that emerges from our calibration exercise.

The other nonstochastic properties of the model seem much more plausible. According to our model, in nonstochastic steady state, C/Y and K/Y equal 0.76 and 2.44, respectively. Using the data discussed in Christiano and Eichenbaum (1992), we find that the sample average values of these variables are 0.73 and 2.65. Next consider the value of n, the fraction of the population who are employed. According to our model, $n = 0.48$. The sample average (1948-1993) of the ratio of employed civilian workers to the civilian non-institutional population over the age of 16 is 0.59. The ratio of total employment (including the military) to the total population is 0.415. Given the ambiguity regarding which measure of the population is appropriate for our model, a value of $n = .48$ seems reasonable. Next, according to the model, l_2 is equal to 0.0004.

Table 3 summarizes the balance sheet of the banking sector in non stochastic steady state. The main things to notice are that (i) consistent with the data, average excess reserves are very small, and (ii) roughly 75% of the bank's assets consist of working capital loans. The remaining assets consist of reserves and loans to fund investment. All of the banks' liabilities consist of demand deposits.

4.2. Impulse Response Functions

In this subsection we discuss the dynamic response of our model economy to a unit shock in ϵ_{x_1} and ϵ_f. To compute these responses, we use the approximate log linear solution procedure discussed in Christiano and Valdivia (1994).

A Shock to the Growth Rate of Money

The three panels in Table 5 report the contemporaneous and lagged responses of several variables to a one percentage point innovation in the growth rate of the monetary base. Consider first the response of short term interest rates (Panel A). In the impact period of the shock, r_{ft} and r_{at} fall by roughly 43 and 40 basis points, respectively, after which they converge to their unchanged non stochastic steady state path from below.

The limited participation mechanism underlying the contemporaneous decline in interest rates assumes that households cannot increase their holdings of currency in response to a positive money shock. As a result, the innovation in the monetary base shows up dollar-for-dollar as a rise in the reserves of banks. This generates a liquidity effect, which exerts downward pressure on the interest rate, as banks lend out their extra reserves. We have assumed that the growth rate of the base is positively autocorrelated, so that a money shock also generates upward pressure on interest rates, via an expected inflation effect. Which effect dominates is a quantitative issue. In our model, the liquidity effect dominates.

The result that a monetary policy shock induces a persistent decline in interest rates, reflects the assumption that it is costly for households to increase their currency holdings. Because of these costs, currency holdings rise to their new steady state path only slowly from below. Throughout the transition period, a relatively high proportion of the base consists of reserves in the banking system. And as long as this is the case, interest rates remain relatively low.

A natural question is: how large are our assumed adjustment costs? Based on the following calculations, we conclude that the costs are very small. We reach this conclusion by computing agents' portfolio decisions when they (sub optimally) ignore adjustment costs and by measuring the amount of time, l_4, that the resulting rapid portfolio adjustments entail. The resulting sequence of time spent on adjusting portfolios, l_{4t}, is a measure of the adjustment costs that the optimal decision rules avoid. We find that the sequence of l_4's computed in this way amount to *less than one minute a week* over the first six months after a one percentage point shock to money growth. Evidently, only very small adjustment costs in M_t/M_{t-1} are needed to generate persistent liquidity effects. Adjustment costs of such small magnitude seem very plausible.

Next, we consider the response of different monetary aggregates to a positive monetary policy shock. According to Table 5, such a shock leads to sizable, persistent increases in bank reserves, $M0$, $M1$, and excess reserves. The increase in $M1$ reflects a rise in bank loans, which generates a rise in demand deposits. Excess reserves rise because the opportunity cost of holding them (r_{ft}) has declined.

A key feature of our results is the differential sensitivity of bank reserves, $M0$ and $M1$ to the monetary policy shock.[7] Initially, $M0$ rises by 0.99%, after which it converges to its new steady state path, which is 1.10 percent above the unshocked path. In contrast, reserves initially rise by more than 6%. This sensitivity reflects the limited participation assumption. In particular, all of the initial increase in the $M0$ must take the form of an increase in bank reserves.

According to Table 5, $M1$ is also more sensitive than $M0$ to a monetary policy shock. Initially $M1$ rises by about 2.2% and then slowly converges to its steady state path from above. The sensitivity of $M1$ reflects a sharp expansion in the 'endogenous' components of $M1$ in response to the policy shock. Specifically, the decline in interest rates following the policy shock is associated with a rise in bank loans for working capital and investment purchases. So, for different reasons, reserves and $M1$ rise more sharply than $M0$ following a positive monetary policy shock.

Next, we consider the response of various real quantities to a positive monetary policy shock. Table 5 reveals that such a shock leads to a rise in consumption, investment, goods output, the total number of people employed and hours worked per employed person (l_{1t}). The intuition for the rise in employment is similar to that underlying the analog result in simple cash in advance limited participation models. Firms must obtain loans from banks to pay labor. By reducing the marginal cost of labor, the fall in interest rates after a positive policy shock leads to a rise in the demand for labor. While there are other potentially offsetting effects, the demand for labor effect is the dominant one in terms of explaining the movement in aggregate employment.

[7]Recall that, absent monetary accommodation to the technology shock and given the limited participation assumption, the response of nonborrowed and total reserves to a monetary policy shock is identical.

Notice that the number of people employed in the banking sector, n_b, declines even though l_{1t} rises. The intuition for the decline in n_b is as follows. After the policy shock, goods output rises, drawing resources - both capital and people - from the banking sector into the goods producing sector. A simple calculation shows that the rise in hours worked in the banking sector does not compensate for the fall in k_{bt} and n_{bt}. However the rise in excess reserves allows total output of the banking sector to expand.

Table 5 also reveals an important shortcoming of our model: the inflation rate rises sharply in the impact period of the shock. Thereafter, inflation falls and converges to its nonstochastic steady state level from below. This response pattern is inconsistent with empirical estimates reported in the literature. For example, an implication of results in Christiano, Eichenbaum and Evans (1994) is that, after a positive monetary policy shock, the inflation rate does not respond for about a year, after which it rises.

A Technology Shock to the Goods Producing Sector

Tables 6 and 7 report the contemporaneous and lagged responses of several variables to a one percent positive shock to the technology for producing goods. Table 6 assumes there is no monetary accommodation via the discount window (i.e., $b_1 = b_2 = 0$), while Table 7 reports results for the case with accommodation, with parameter values reported in Table 1.

According to Table 6, a shock to x_{ft} leads to a persistent rise in employment, average hours worked, output, consumption and investment. The intuition for these effects is very similar to that underlying the effects of a technology shock in standard Real Business Cycle models.

On the monetary side of the economy, the shock to x_{ft} stimulates a rise in the demand for loans by firms. Banks supply the increased loans, which show up as an increase in $M1$, by hiring more factors of production and, in the impact period of the shock, running down excess reserves. In the impact period of the shock, the banking system cannot increase loans except by reducing excess reserves. This reflects the no-accommodation assumption on the discount window, as well as the limited participation assumption. After a one period delay, reserves flow into the banking system as households respond to higher interest rates by decreasing their currency holdings, and increasing deposits, A. Banks use these reserves to

increase loans and replenish excess reserves. The net result is that technology shocks induce positive co-movements between reserves, $M1$ and interest rates.

Notice also that, according to the model, both technology and monetary policy shocks, induce positive comovements between output and various monetary aggregates. So, the model captures the endogeneity of broad monetary aggregates to non-policy shocks emphasized by Friedman and Schwartz (1963), and King and Plosser (1984), among others. At the same time, because of the limited participation assumption, $M1$ responds more sharply to output, at least contemporaneously, than does reserves. This differential sensitivity is, in principle, capable of rationalizing the fact, documented in section 2, that $M1$ is more highly correlated (at least contemporaneously) with output than is nonborrowed reserves.

In the previous experiment, a shock to technology does not change the monetary base. Analyzing this case is useful for building intuition about the effects of a technology shock. It also shows why it is important to have a feedback component to monetary policy. Without this, we could not account for the observed positive correlation between the interest rate and the monetary base. With accommodation, the model has a source of positive co-movements between the base and interest rates. That this is the case is evident from Table 7. Also notice from that table that, with $b_2 < 0$, the base quickly reverts to its unperturbed steady state path, as the borrowed reserves injected at the time of the technology shock are withdrawn.

For the most part, the responses reported in Table 7 are just a simple combination of the responses in Tables 5 and 6. Still, there are five features of Table 7 that we wish to emphasize. First, the response of nonborrowed reserves is now sharply different from that of total reserves. For example, in the impact period of the shock nonborrowed reserves remain unchanged, while total reserves are up 5.4 percent. All of this rise in total reserves reflects the increase in borrowed reserves. Second, excess reserves no longer fall - instead, they rise sharply - in the period of the technology shock. Third, the base and $M1$ rise by more when there is monetary accommodation. Fourth, the borrowed reserves policy has the effect of reducing the equilibrium interest rate response to a technology shock. In this sense, the discount window acts to smooth interest rates. Fifth, the borrowed reserves policy has the effect of increasing the output response of a technology shock. Christiano and Eichenbaum (1994) analyze the last two phenomena in a cash-in-advance, limited participation economy.

4.3. Second Moment Properties

In this subsection we discuss the second moment properties of the model. We begin by considering the implications of the model for real variables. We then turn to the monetary properties of the model.

4.3.1. Real Variables

Tables 7a and 7b report selected second moments of real variables for the U.S. data and for our model, respectively. The key property to note here is that our model shares most of the strengths and weaknesses of standard real business cycle models. For example, it accurately predicts that consumption is smooth relative to income, and that investment is volatile. Like most real business cycle models, it fairs less well in accounting for aspects of labor market fluctuations. For example, it under predicts the volatility of employment and hours worked per employed person and over predicts the correlation of productivity with output. A success of the model is that it accurately predicts that hours per person is about half as volatile as employment. Still the main finding here is that the real variables in our model economy behave very much as they do in standard real business cycle models. In fact, when we shut down the stochastic components of the monetary base, we found that the second moment properties reported in Table 7b were virtually unaffected.

4.3.2. Monetary Variables

We now turn to the implications of our model for monetary variables. We first consider the sign switch observations. We then turn to the money-output and interest rate-output correlations.

Panel A of Table 9 presents estimates of the correlation between the federal funds rate and various monetary aggregates (see the last three rows). The analog correlations for the baseline model are presented in Panel B. In comparing the numbers in these tables, it is useful to bear in mind that the model time period is one-half the data sampling period.

Fourth, key features of these results are worth noting. First, the model correctly accounts for the ranking of the contemporaneous correlations of the various monetary aggregates with

the federal funds rate. Going from most to least highly correlated with r_a, this ranking is given by $M1$, the base, reserves and nonborrowed reserves, respectively. Second, the model correctly accounts for the fact that r_a displays a weak correlation with the first three of these monetary aggregates and displays a strong negative correlation with nonborrowed reserves. From a quantitative point of view, the model closely matches the contemporaneous correlation between these variables. Third, the model reproduces a basic feature of the correlation functions between r_a and the base, and between r_a and $M1$. Specifically, the model is consistent with the fact that r_a is positively correlated with lagged values of the base and $M1$, but negatively correlated with their future values. Fourth, at a quantitative level, the model is less successful at reproducing the negative correlation between r_a and future nonborrowed reserves and $M1$.

To understand this last shortcoming recall that, in our model, technology shocks contribute to a positive correlation between r_a and future monetary aggregates, while monetary shocks contribute to a negative correlation. The first effect arises because a positive technology shock leads to a contemporaneous rise in the interest rate and to a persistent rise in output, as well as nonborrowed reserves and $M1$. The second effect arises because a positive monetary policy shock leads to a fall in the current interest rate and a persistent rise in output, as well as nonborrowed reserves and $M1$. The shortcoming of the model reflects the relative importance of the role of technology shocks. This suggests two remedies to the problem: make the dynamic impact of technology shocks on output less important and/or make the dynamic impact of a monetary policy shock on output less important.[8] The base does better with respect to these correlations because the technology shock does not have an important dynamic effect on $M0$. This reflects our discount window policy, according to which reserves that are injected in the impact period of a shock are withdrawn thereafter.

To help convey intuition about the features of our model which allow it to account for the sign switch, Panels B and C of Table 9 report results for two variants of the model. Panel B pertains to a variant of the baseline model in which there are no borrowed reserves, i.e.

[8]There is a third option: increase the impact effect of a monetary policy shock on the interest rate and/or decrease the impact effect of a technology shock on the interest rate. We are somewhat skeptical of this solution because the contemporaneous interest rate effect of a technology shock is already quite low in the model, while the contemporaneous interest rate effect of a monetary policy shock is high.

$b_1 = b_2 = 0$. Panel C pertains to a variant of the baseline model in which (i) the limited participation assumption does not hold, and (ii) there are no adjustment costs associated with changing currency holdings ($\Lambda_1 = \Lambda_2 = 0$.) Panel B indicates that setting the parameters b_1 and b_2 to zero raises the correlation between r_a and the monetary base, reflecting the fact that the only source of endogeneity in the base is borrowed reserves. Absent this source, the base comoves negatively with r_a.

Comparing the results in Panels B and D allows us to evaluate the impact of the limited participation assumption on our analysis. The key thing to note is that all the contemporaneous correlations are positive. This is because, absent a liquidity effect, exogenous shocks to the growth rate of the base drive interest rates up, not down. So, in our analysis limited participation is a necessary condition to account for the sign switch.

We now turn to an analysis of the correlation between the interest rate and output. First, notice that the model does well at matching the contemporaneous correlation between r_a and output. At a qualitative level, it reproduces the fact that the correlation between r_a and past output is much greater than the correlation between r_a and future output. However, it does not reproduce the strong negative correlation between r_a and future output that is observed in the data. This reflects the relative importance of technology shocks in our model.

Finally, we turn to table 10, which presents the correlations between the various monetary aggregates in our model and output. There are three key features to note. First, the model correctly accounts for the fact that the monetary base and $M1$ lead output, in the sense that they are positively correlated with future output. Second, the model accounts for the ranking of the contemporaneous correlations of the various monetary aggregates with output. Going from most to least highly correlated with output, this ranking is given by $M1$, the base, reserves and nonborrowed reserves, respectively. Third, the model correctly accounts for the positive contemporaneous correlation between output and $M1$ and the base, although it considerably overstates it. Finally, it does not account for the negative contemporaneous correlation in the data between nonborrowed reserves and output. This may reflect omitted shocks or a misspecified monetary policy rule.

5. Conclusion

This paper showed that broad monetary aggregates like bank reserves, M0 and M1, are positively correlated and nonborrowed reserves are negatively correlated, with current and future values of the interest rate. In addition, the paper presents a model which quantifies a particular explanation for this 'sign switch' in the dynamic relation between various monetary aggregates and short term interest rates.

Our model accounts for the negative correlation between nonborrowed reserves and the interest rate as reflecting (i) the relative importance of exogenous money supply shocks in nonborrowed reserves and (ii) the importance of liquidity effects in the monetary transmission mechanism.

In order for our argument to be fully convincing, we must show that our model at least reproduces the salient features of post war US business cycle data. We intend to investigate whether this is the case in a future draft of the paper using formal econometric methods. Our initial results suggest that we must modify the model so that monetary policy shocks have more persistent effects on output.

6. References

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Table 1: Model parameters*

Period of model (fraction of year): 0.1

Table 1: Model parameters*

Period of model (fraction of year): 0.11

Household	Goods Producing	Banks	Monetary Authority
$\beta^{-1} = 1.04$	$\alpha = 0.36$	$\tau = 0.06$	$x = 0.065$
$\varphi = -0.5$	$A_f = 1$	$1 - \zeta = 0.0206$	$\rho_x = 0.1$
$\theta = 0.488$	$A_b = 1074.76$		$\sigma_{x_1} = 0.0038$
$J = .0036$	$\mu_z = 0.016$		$b_1 = 3.0$
$\gamma = 2.10$	$\rho_f = 0.50$		$b_2 = -2.1$
$\delta = 0.08$	$\sigma_f = 0.0097$		$\rho = .3$
$\nu_0 = 0.18$			
$\nu_1 = 3.41$			
$\Lambda_1 = 1$			
$\Lambda_2 = 0.3$			

* Parameters with a time dimension expressed at an annual rate

Table 2: Some properties of non stochastic steady state*

K_b/K	.001	l_1	.48	π	4.8%	D/M	3.18	PY/M	21.6
N_b/N	.001	l_2	.004	r_f	8.3%	E/(PC)	.0004	PY/M0	18.0
K/Y	2.44	l_3	.015	r_a	6.9%	D/(PC)	.194	PY/M1	5.2
C/Y	.76	n	.48	r_k	14%	M1/M	4.31		
		nl_1	.23			M1/M0	3.36		

* Variables with a time dimension expressed at an annual rate

Table 3: Banking sector balance sheet (non stochastic steady state)*

Assets		Liabilities	
Reserves	.062	Demand deposits	1.0
Required	.060		
Excess	.002		
Working capital	.755		
Wage loans	.483		
Capital rental loans	.272		
Investment loans	.182		

* Numbers expressed as a fraction of total bank assets

Table 4: Response to a money supply shock*

Panel A: Interest rates, inflation and reserves

	r_a	r_f	π	NBR	ER	TR
0	- 0.40	- 0.43	1.76	6.01	93.57	6.01
1	- 0.37	- 0.39	- 0.32	3.59	48.55	3.59
2	- 0.17	- 0.18	- 0.18	2.25	23.03	2.25
3	- 0.08	- 0.08	- 0.08	1.62	10.97	1.62
4	- 0.04	- 0.04	- 0.04	1.34	5.46	1.34
5	- 0.02	- 0.02	- 0.02	1.21	2.95	1.21
6	- 0.01	- 0.01	- 0.01	1.15	1.82	1.15
7	- 0.00	- 0.00	- 0.00	1.12	1.31	1.12
8	- 0.00	- 0.00	- 0.00	1.11	1.08	1.11
9	- 0.00	- 0.00	- 0.00	1.10	0.98	1.10

Panel B: Monetary aggregates

	M	A	Base	M1	Loans
0	0	0	0.99	2.20	2.68
1	0.60	3.07	1.09	1.65	1.87
2	0.87	2.24	1.10	1.36	1.46
3	1.00	1.64	1.10	1.22	1.27
4	1.06	1.35	1.10	1.16	1.18
5	1.08	1.21	1.10	1.13	1.14
6	1.09	1.15	1.10	1.12	1.12
7	1.10	1.12	1.10	1.11	1.11
8	1.10	1.11	1.10	1.11	1.11
9	1.10	1.10	1.10	1.11	1.11

Panel C: Real quantities

	C	I	Y	n_f	n_b	l_1
0	0.14	1.07	0.37	0.31	- 0.38	0.17
1	0.00	0.13	0.03	0.03	- 0.41	0.01
2	0.01	0.06	0.02	0.01	- 0.19	0.01
3	0.01	0.02	0.01	0.00	- 0.09	0.00
4	0.01	0.01	0.01	0.00	- 0.04	0.00
5	0.01	- 0.00	0.00	- 0.00	- 0.02	- 0.00
6	0.01	- 0.00	0.00	- 0.00	- 0.01	- 0.00
7	0.01	- 0.01	0.00	- 0.00	- 0.01	- 0.00
8	0.01	- 0.01	0.00	- 0.00	- 0.00	- 0.00
9	0.01	- 0.01	0.00	- 0.00	- 0.00	- 0.00

*Response to a one percentage point innovation in x_1. Entries for r_a, r_f and π report the percentage point deviation of these variables from their unshocked steady state path. All other entries report percent deviations from their unshocked steady state paths.

Table 5: Response to a technology shock without monetary accommodation*

Panel A: Interest rates, inflation and reserves

	r_a	r_f	π	NBR	ER	TR
0	0.54	0.58	- 0.49	0	- 24.49	0
1	0.31	0.33	0.38	1.21	10.21	1.21
2	0.07	0.08	0.14	1.14	14.84	1.14
3	- 0.00	- 0.00	0.03	0.80	11.31	0.80
4	- 0.02	- 0.02	- 0.00	0.50	6.90	0.50
5	- 0.02	- 0.02	- 0.01	0.28	3.51	0.28
6	- 0.01	- 0.01	- 0.01	0.15	1.29	0.15
7	- 0.01	- 0.01	- 0.01	0.06	- 0.06	0.06
8	- 0.00	- 0.00	- 0.00	0.02	- 0.83	0.02
9	- 0.00	- 0.00	- 0.00	- 0.01	- 1.25	- 0.01

Panel B: Monetary aggregates

	M	A	Base	M1	Loans
0	0	0	0	0.67	0.93
1	- 0.24	1.26	0	0.62	0.86
2	- 0.23	1.19	0	0.44	0.62
3	- 0.16	0.84	0	0.29	0.40
4	- 0.10	0.52	0	0.18	0.25
5	- 0.06	0.29	0	0.11	0.16
6	- 0.03	0.15	0	0.07	0.10
7	- 0.01	0.07	0	0.05	0.07
8	- 0.00	0.02	0	0.04	0.05
9	0.00	- 0.01	0	0.03	0.04

Panel C: Real quantities

	C	I	Y	n_f	n_b	l_1
0	0.20	4.78	1.31	0.26	2.22	0.14
1	0.22	2.98	0.89	0.31	1.18	0.17
2	0.14	1.49	0.47	0.15	0.49	0.09
3	0.10	0.73	0.25	0.07	0.20	0.04
4	0.07	0.35	0.14	0.03	0.07	0.02
5	0.06	0.15	0.08	0.01	0.02	0.01
6	0.06	0.05	0.05	- 0.00	0.00	- 0.00
7	0.05	- 0.00	0.04	- 0.01	- 0.01	- 0.00
8	0.05	- 0.03	0.03	- 0.01	- 0.01	- 0.01
9	0.05	- 0.04	0.03	- 0.01	- 0.01	- 0.01

*Response to a one percentage point innovation in $x_f, b_1 = b_2 = 0$. Entries for r_a, r_f and π report the percentage point deviation of these variables from their unshocked steady state path. All other entries report percent deviations from their unshocked steady state paths.

Table 6: Response to a technology shock with monetary accommodation*

Panel A: Interest rates, inflation and reserves

	r_a	r_f	π	NBR	ER	TR
0	0.05	0.05	- 0.37	0	89.65	5.41
1	0.13	0.14	0.24	0.64	32.83	2.23
2	0.06	0.06	0.12	0.73	16.21	1.17
3	0.01	0.01	0.04	0.59	9.18	0.69
4	- 0.00	- 0.00	0.01	0.41	5.02	0.40
5	- 0.01	- 0.01	- 0.00	0.26	2.29	0.22
6	- 0.01	- 0.01	- 0.00	0.16	0.54	0.11
7	- 0.00	- 0.00	- 0.00	0.10	- 0.54	0.05
8	- 0.00	- 0.00	- 0.00	0.06	- 1.18	0.01
9	- 0.00	- 0.00	- 0.00	0.04	- 1.53	- 0.01

Panel B: Monetary aggregates

	M	A	Base	M1	Loans
0	0	0	0.89	1.84	2.20
1	- 0.12	6.25	0.27	0.84	1.06
2	- 0.14	2.40	0.08	0.45	0.60
3	- 0.11	1.07	0.02	0.27	0.36
4	- 0.07	0.53	0.01	0.16	0.23
5	- 0.04	0.27	0.00	0.10	0.14
6	- 0.02	0.13	0.00	0.07	0.10
7	- 0.01	0.05	0.00	0.05	0.07
8	- 0.00	0.01	0.00	0.04	0.05
9	0.00	- 0.01	0	0.03	0.04

Panel C: Real quantities

	C	I	Y	n_f	n_b	l_1
0	0.39	6.12	1.77	0.64	1.75	0.36
1	0.23	3.04	0.91	0.32	0.99	0.18
2	0.15	1.49	0.47	0.15	0.48	0.09
3	0.10	0.72	0.25	0.07	0.21	0.04
4	0.08	0.33	0.14	0.03	0.09	0.02
5	0.07	0.14	0.09	0.01	0.03	0.00
6	0.06	0.04	0.06	- 0.00	0.00	- 0.00
7	0.06	- 0.01	0.04	- 0.01	- 0.01	- 0.00
8	0.06	- 0.03	0.04	- 0.01	- 0.01	- 0.01
9	0.06	- 0.05	0.03	- 0.01	- 0.01	- 0.01

*Response to a one percent innovation in x_f,where b_1, b_2, ρ are as in table 1. Entries for r_a, r_f and π report the percentage point deviation of these variables from their unshocked steady state path. All other entries report percent deviations from their unshocked steady state paths.

Table 7a: Cyclical behavior of the U.S. economy

1954:1 - 1988:2, sample interval: quarterly

Correlation of x_t with output$_{t-k}$

Variables x	Std. Dev.	$k=-2$	$k=-1$	$k=0$	$k=1$	$k=2$
Gross national product	1.74%	0.63	0.85	1.00	0.85	0.63
Consumption expenditures	0.73	0.71	0.81	0.81	0.66	0.45
Services & nondurable goods	0.49	0.67	0.76	0.76	0.63	0.47
Durable goods	2.92	0.65	0.74	0.77	0.60	0.37
Fixed investment	3.17	0.65	0.83	0.90	0.81	0.60
Hours (household survey)	0.86	0.44	0.68	0.86	0.86	0.75
Hours (establishment survey)	0.97	0.39	0.67	0.88	0.92	0.81
Hours per worker	0.32	0.48	0.64	0.69	0.58	0.43
Civilian employment	0.62	0.36	0.61	0.82	0.89	0.82
GNP/Hours (household)	0.52	0.49	0.51	0.51	0.21	-0.03
GNP/Hours (establishment)	0.48	0.53	0.43	0.31	-0.08	-0.32

Data source: Kydland and Prescott (1991), table 3. Data have been logged and hp filtered. Column1 reports standard deviations relative to the standard deviation of output.

Table 7b: Cyclical behavior of the model economy

Correlation of x_t with output$_{t-k}$

Variables x	Std. Dev.	$k=-2$	$k=-1$	$k=0$	$k=1$	$k=2$
Gross national product	1.77%	0.08	0.38	1.00	0.38	0.08
Consumption	0.22	0.01	0.33	0.99	0.44	0.15
Fixed investment	3.47	0.09	0.39	1.00	0.37	0.06
Hours	0.58	0.09	0.39	0.99	0.37	0.06
Hours per worker	0.21	0.09	0.39	0.99	0.37	0.06
Employment	0.37	0.09	0.39	0.99	0.37	0.06
GNP/Hours	0.43	0.06	0.36	0.99	0.39	0.10

*Data have been logged and hp filtered. Sample interval: model period (one-half sampling interval). Column1 reports standard deviations relative to the standard deviation of output.

Table 8: Volatility of nominal variables*

Panel A: Interest rates, inflation and reserves

r_a	$\hat{r}_a$	r_f	π	NBR	TR
0.0024	0.0019	0.0025	0.0080	0.0249	0.0572

Panel B: Monetary aggregates

Currency velocity	Base	M1	Base velocity	M1 velocity
0.0169	0.0100	0.0199	0.0079	0.0042

* Variables with a time dimension expressed in units of model sampling interval

Table 9: Correlation Properties: Money, Output and Interest Rates

Panel A: U.S. data

Correlation of r_{at} with:

	x_{t+2}	x_{t+1}	x_t	x_{t-1}	x_{t-2}
Output	- 0.18	0.09	0.36	0.54	0.59
M1	- 0.32	- 0.24	- 0.05	0.14	0.24
Base	- 0.19	- 0.11	0.06	0.21	0.27
NBR	- 0.34	- 0.48	- 0.55	- 0.41	- 0.22

* Monetary data have been logged and all data have been hp filtered. Sample interval: quarterly.

Panel B: Baseline model

Correlation of r_{at} with:

	x_{t+2}	x_{t+1}	x_t	x_{t-1}	x_{t-2}
Output	0.02	0.15	0.36	0.48	0.11
M1	- 0.08	- 0.06	0.03	0.32	0.15
Base	- 0.24	- 0.22	0.00	0.41	0.29
Reserves	- 0.02	- 0.03	0.02	0.29	0.10
NBR	0.06	- 0.11	- 0.58	- 0.44	- 0.12

*Monetary data have been logged and all data have been hp filtered. Sample interval: model period.

Panel C: Baseline model, no monetary accommodation

Correlation of r_{at} with:

	x_{t+2}	x_{t+1}	x_t	x_{t-1}	x_{t-2}
Output	0.16	0.50	0.89	0.28	- 0.11
M1	0.19	0.33	0.37	0.04	- 0.09
Base	- 0.15	- 0.18	- 0.19	- 0.03	0.11
Reserves	0.34	0.35	- 0.14	- 0.24	- 0.15
NBR	0.34	0.35	- 0.14	- 0.24	- 0.15

*Monetary data have been logged and all data have been hp filtered. Sample interval: model period.

Panel D: Baseline model, monetary accommodation, no limited participation

Correlation of r_{at} with:

	x_{t+2}	x_{t+1}	x_t	x_{t-1}	x_{t-2}
Output	0.02	0.33	0.96	0.59	0.24
M1	0.00	0.29	0.93	0.56	0.23
Base	- 0.10	0.09	0.75	0.48	0.21
Reserves	0.00	0.31	0.96	0.59	0.25
NBR	0.44	0.88	0.79	0.37	0.08

*Monetary data have been logged and all data have been hp filtered. Sample interval: model period.

Table 10: Correlation Properties, Money and Output

Panel A: U.S. data

Correlation of x_t with output_{t-k}

	$k=-2$	$k=-1$	$k=0$	$k=1$	$k=2$
M1	0.33	0.34	0.29	0.18	0.10
Base	0.37	0.39	0.34	0.26	0.20
NBR	0.10	- 0.06	- 0.22	- 0.32	- 0.34

* All variables have been logged and hp filtered. Sample interval: quarterly.

Panel B: Baseline model

Correlation of x_t with output_{t-k}

	$k=-2$	$k=-1$	$k=0$	$k=1$	$k=2$
M1	0.06	0.34	0.92	0.32	0.07
Base	0.08	0.33	0.84	0.15	- 0.05
Reserves	0.08	0.35	0.94	0.29	0.06
NBR	- 0.07	- 0.02	0.16	0.35	0.30

* All variables have been logged and hp filtered. Sample interval: model period.

Figure 1:
Dynamic Correlations Money the Funds Rate

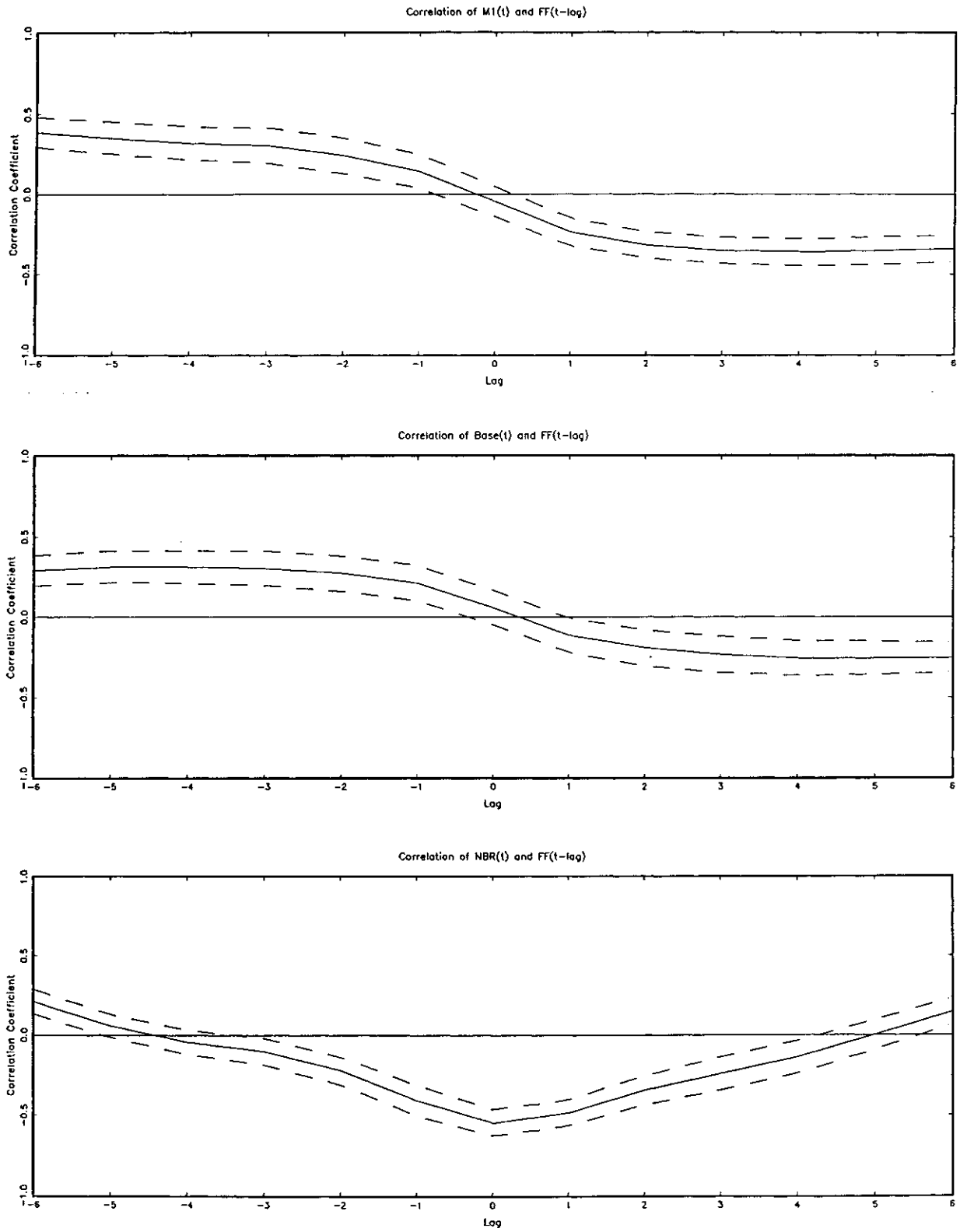

Figure 2:
Dynamic Correlations Money and Output

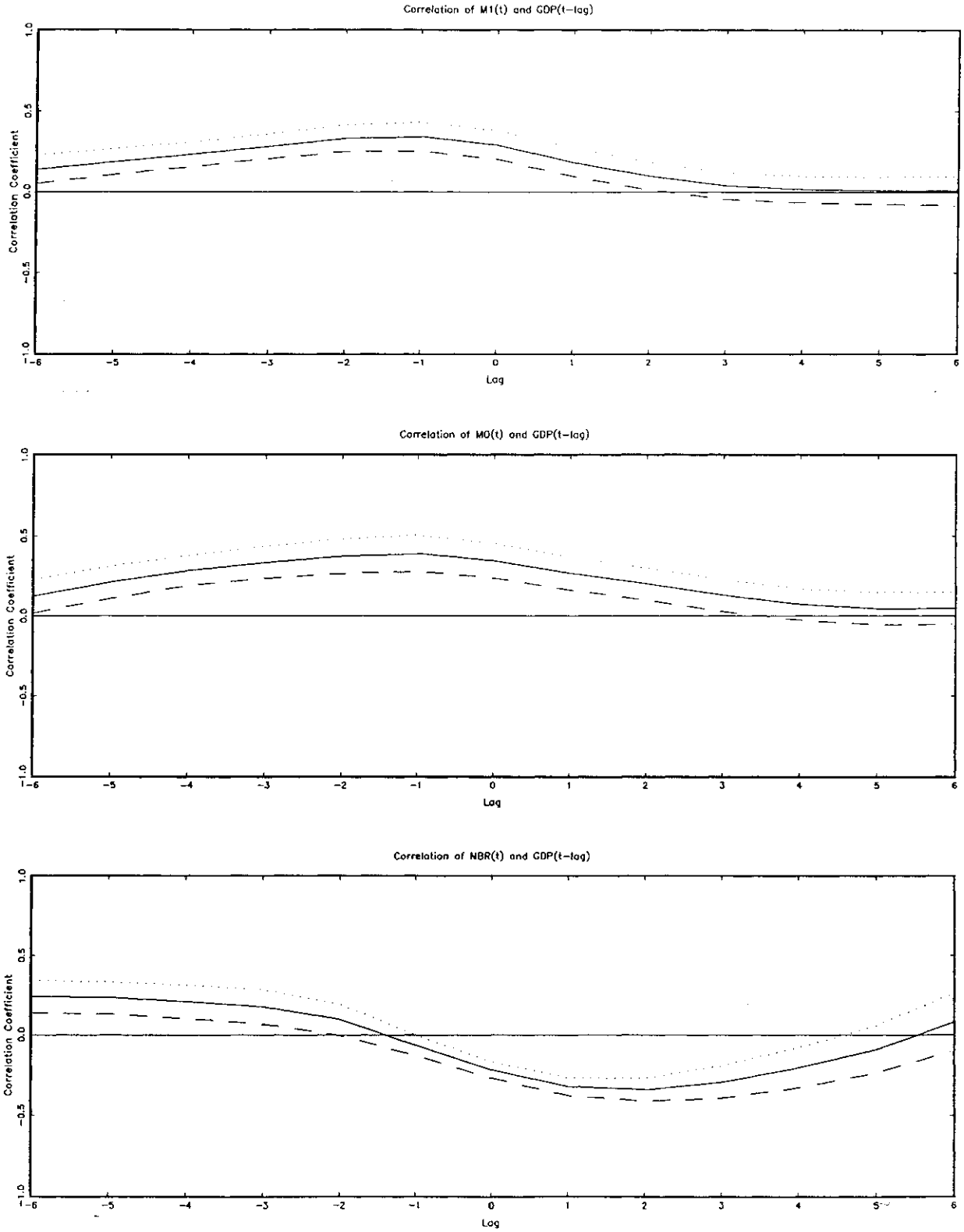
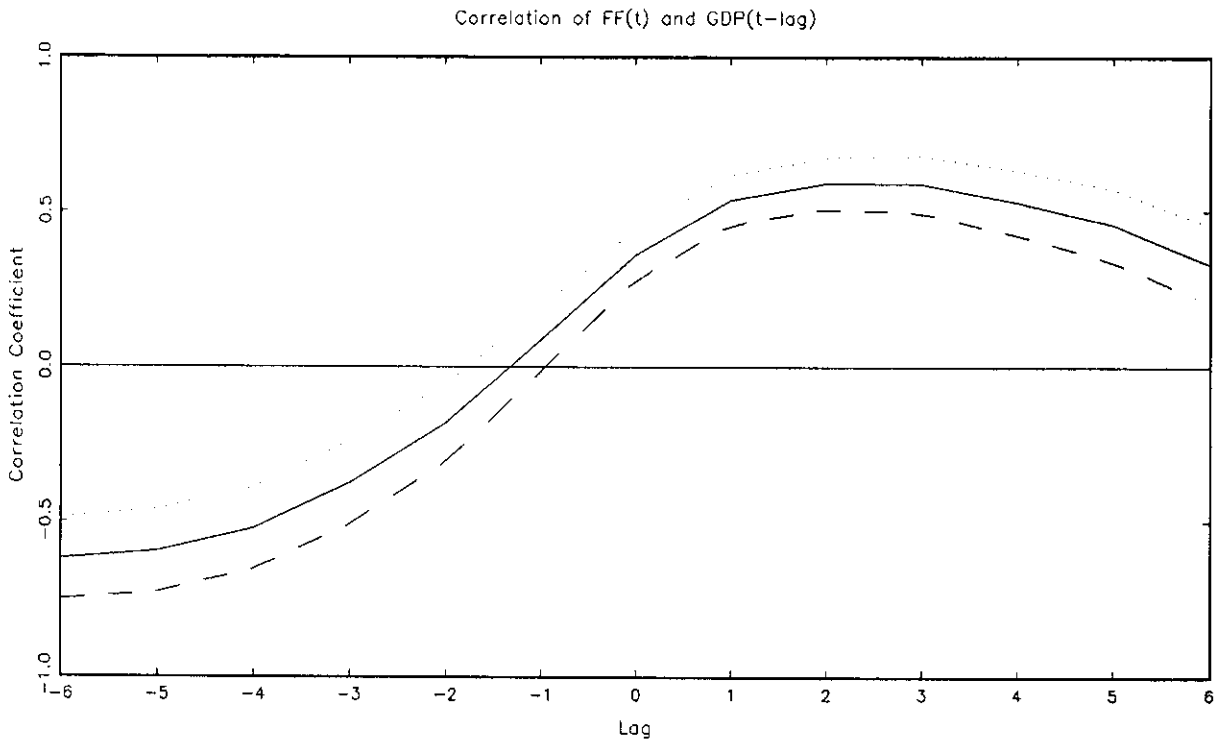
Figure 3:
Dynamic Correlations the Funds Rate and Output