Liquidity effects, the monetary transmission mechanism, and monetary policy

Lawrence J. Christiano and Martin Eichenbaum

Conventional wisdom holds that an expansionary monetary policy shock generates a persistent decline in short term interest rates and a persistent increase in the level of employment and output. Using different styles of analysis, Bernanke and Blinder (1992), Christiano and Eichenbaum (1992a,c), Eichenbaum (1992), Gali (1992), King and Watson (1992), Sims (1992), and Strongin (1992) provide strong empirical support in favor of the conventional view. These findings pose an important challenge to macroeconomists. This is because existing quantitative, general equilibrium business cycle models which allow for capital accumulation are inconsistent with the conventional view. For example, King (1991) and King and Watson (1992) discuss the difficulty of generating a negative interest rate response to positive money supply shocks in Keynesian type models with sticky wages and/or sticky prices. This is also the case for real business cycle models in which money is introduced simply by imposing cash in advance constraints on agents (as in Lucas [1984], Greenwood and Huffman [1987], Cooley and Hansen [1989], or Christiano [1991]), or by incorporating a transactions demand for money into the analysis (as in Kydland [1989], den Haan [1991], or Marshall [1992]). A generic implication of these monetized real business cycle models is that, if money growth displays positive persistence, then unanticipated increases in the supply of money drive interest rates up, not down. This is because, in these models, money shocks affect interest rates exclusively through an anticipated inflation effect. So, to drive interest rates down, a positive shock to the supply of money would have to signal less inflation in the future. But to obtain this result one must make grossly counterfactual assumptions regarding the law of motion for the money supply. Specifically, one would have to assume that the growth rate of money displayed substantial negative serial correlation.

In our opinion, any convincing explanation of the empirical facts will involve business cycle models in which money supply shocks generate significant, persistent liquidity effects. Recently, a number of researchers have made progress in constructing such models. For convenience we refer to these models as *liquidity effect models*. Specifically, Lucas (1990), Christiano (1991), Christiano and Eichenbaum (1992a), Fuerst (1992a), Grilli and Roubini (1992), and Schlagenhauf and Wrase (1992) have constructed general equilibrium models in which purely *transitory* liquidity effects arise. In these models, the liquidity effect can dominate the initial expected inflation effect associated with a change in the growth rate of money. Under these circumstances, the contemporaneous effect of an unanticipated increase in the money supply is a fall in the nomi-

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nal interest rate along with an increase in employment and output.

In this article, we seek to accomplish three objectives. First, we discuss the basic mechanisms at work in these liquidity effect models. Second, we investigate one way of generating persistent (as opposed to purely transitory) liquidity effects. We argue that once a simplified version of the model in Christiano and Eichenbaum (1992a) is modified to allow for small costs of adjusting sectoral flows of funds, positive money supply shocks generate long lasting, significant liquidity effects as well as persistent increases in aggregate economic activity. Finally, we discuss some of the policy implications of this class of models.

The model we analyze builds on a tradition of theoretical papers which begins with the premise that the key to understanding the effects of money supply shocks lies in the differential impacts that such shocks have on different agents in the economy (Grossman and Weiss [1983], Rotemberg [1984], Woodford [1987], and Baxter, Fisher, King, and Rouwenhorst [1990]). Following Lucas (1990) and Fuerst (1992a), we focus on firms and financial intermediaries as the key subset of agents who absorb disproportionally large shares of money supply shocks. To generate this result, we assume that households make their nominal consumption-savings decision before observing the current period realization of monetary policy. This allows us to capture in a simple way the notion that firms and financial intermediaries respond relatively more quickly than households do to movements in asset prices induced by open market operations.

Consistent with the fact that actual open market operations involve the financial sector of the economy, we suppose that cash injections go to financial intermediaries. These intermediaries are assumed to be in constant contact with goods producing firms who need working capital, that is, cash, to fund their ongoing operations. As long as the nominal interest rate is positive, financial intermediaries will lend out all of the cash at their disposal. When a positive money supply shock occurs, households are out of the picture, at least in the short run. This means that firms *must* absorb a disproportionally large share of unanticipated cash injections. To induce firms to do so voluntarily, the interest rate must fall. The downward pressure on interest rates continues as long as an unusually large percentage of the economy's cash flows through the financial sector.

The same frictions in agents' environments that give rise to a liquidity effect also imply that constant growth rate rules for the money supply, of the type advocated by Friedman (1968), will not be optimal. This is because, in our model, it is less costly for the monetary authority to direct cash to financial intermediaries (and ultimately to firms) via open market operations than it is for private agents to do so via adjustments in their nominal consumption-savings decisions. So it can be welfare improving for the monetary authority to accommodate various shocks which impact on agents' environments. To make this point concrete, we analyze the response of our model economy to technology shocks which affect the marginal productivity of labor and capital. A key result is that, absent monetary accommodation, contemporaneous aggregate employment does not increase in response to a positive technology shock. The problem is that the extra working capital necessary to fund an increase in employment is simply not forthcoming sufficiently quickly from the household sector. Without a change in the money supply, interest rates rise dramatically and valuable social opportunities are wasted. As an alternative to inaction, the monetary authority could pursue a version of the Real Bills Doctrine in which the money supply is increased in response to unanticipated improvements in real production opportunities. In our model, when such a policy is pursued, contemporaneous employment and output do increase in response to favorable technology shocks. Transitory opportunities do not go unexploited.

The previous finding is suggestive along on a number of dimensions. First, the perspective on monetary policy provided by our version of the Real Bills Doctrine captures the spirit of the Federal Reserve Act which directs the central bank to "... furnish an elastic currency, to afford means of rediscounting commercial paper..." (Board of Governors [1988]). Second, in our example, accommodative monetary policy has the effect of smoothing nominal interest rates. Thus, it provides a possible rationale for interest rate smoothing rules of the sort allegedly pursued by the Federal Reserve in much of the post war era (Goodfriend, [1991]). Third, with costs to adjusting sectoral flows of funds, even fully anticipated changes in the money supply (say, a period in advance) generate liquidity effects. Because of this, more fully developed versions of the model could perhaps rationalize seasonal smoothing of interest rates by the Federal Reserve of the sort documented in Mankiw and Miron (1991).

A simple model with liquidity effects

We begin by considering a simplified version of the model in Christiano and Eichenbaum (1992a). In this model, optimizing households, financial intermediaries, and firms interact in perfectly competitive markets. For now we suppose that the only source of uncertainty in agents' environments pertains to the realization of monetary policy. Later, when we discuss the policy implications of the model, we also allow for shocks to the aggregate production technology.

At the beginning of each period, the representative household possesses the economy's entire beginning of period money stock, M_t. The household allocates Q_t dollars to time t purchases of the consumption good, C_t, and lends the rest, $M_t - Q_t$, to financial intermediaries. In addition, the household must decide on how much time, L_t, to work for firms. The household ranks alternative streams of consumption and leisure according to the expected value of the criterion:

$$(1)\quad \sum_{t=0}^{\infty} \beta^t U(C_t, L_t),$$

where $U(C_t, L_t)$ is given by,

$$(2)\quad U(C_t, L_t) = (1-\gamma)\ln(C_t) + \gamma \ln(T - L_t).$$

The parameters β and γ are scalars between zero and one and T is the household's endowment of time.

In period t, the household faces a cash in advance constraint on nominal consumption expenditures:

$$(3)\quad P_t C_t \leq Q_t + W_t L_t.$$

Here P_t and W_t denote the period t dollar price of goods and labor, respectively. According to (3), consumption purchases must be fully financed with cash that comes from two sources: Q_t and wage earnings, $W_t L_t$. In addition, the household must obey its budget constraint,

$$(4)\quad M_{t+1} = R_t(M_t - Q_t) + D_t + F_t + (Q_t + W_t L_t - P_t C_t).$$

The variable R_t denotes the gross interest rate in period t while F_t and D_t denote period t dividends received from firms and financial intermediaries, respectively.

The household maximizes (1) subject to (2), (3), and (4) by choice of contingency plans for L_t, C_t, and Q_t. Throughout we assume that the contingency plans for L_t and C_t are functions of all model variables dated t and earlier. In the *basic liquidity model*, the household's contingency plan for Q_t is not allowed to be a function of the period t realization of monetary policy, that is, the household decides how much money to send to the financial sector before seeing the realization of time t monetary policy. This assumption is intended to capture, in an analytically convenient way, institutional and other factors which constrain households' choices of Q_t, at least in the short run. Institutional considerations include the fact that a nontrivial fraction of M_t is held by firms and financial intermediaries in the form of retained earnings or pension funds and cannot be readily allocated by households to change Q_t. In addition, a variety of fixed costs associated with portfolio decisions, such as those stressed by Akerlof (1979), render it suboptimal for households to continually readjust their nominal consumption-savings plans. To illustrate the impact of the assumed rigidity in Q_t, we also analyze a model which abstracts from that rigidity. Specifically, we investigate the *basic cash in advance model*, where Q_t is allowed to be a function of period t monetary policy.

To simplify the analysis, we suppose that the money supply changes via lump sum cash injections to perfectly competitive financial intermediaries. This means that the representative financial intermediary has two sources of funds: cash received from the household sector, $M_t - Q_t$, and lump sum injections of cash by the monetary authority, X_t. These funds are lent over the period in perfectly competitive markets to firms at the gross interest rate, R_t. The financial intermediary's net cash position at the end of the period is distributed, in the form of dividends, to the financial intermediary's owner, the household, after the consumption good market has closed.

New goods are produced by perfectly competitive firms via the production function,

$$(5)\quad f(K_t, L_t) = AK_t^{\alpha}\ (z_t L_t)^{1-\alpha} + (1-\delta)K_t,$$

where $0 < \alpha < 1$, $0 < \delta < 1$ and A is a positive scalar. Here K_t is the beginning of period t stock of capital, δ is the rate of depreciation on capital, and $f(K_t, L_t)$ denotes new period t output plus the undepreciated part of capital. The variable z_t denotes the time t state of technology. For now we suppose that z_t grows at the constant geometric rate $\mu > 0$. Firms must borrow working capital from financial intermediaries to cover their payments to labor. Loans must be repaid to the financial intermediaries at the end of period t. Consequently, the total period t cost associated with hiring labor equals $R_t W_t L_t$.

Firms own the stock of capital, which evolves according to

$$(6)\quad K_{t+1} = (1-\delta)K_t + I_t,$$

where I_t denotes period t gross investment. Unlike labor, capital is assumed to be a credit good, so that firms need not borrow funds from the financial intermediary to finance investment activities.[1] At the end of the period, after the consumption good market closes, the firm's net cash holdings are distributed to its owner, the household. The perfectly competitive firm maximizes the expected value of its dividends by contingency plans which specify L_t as a function of model variables dated period t and earlier, and I_t as a function of model variables dated t–1 and earlier. This timing specification captures the idea that employment decisions can be revised quickly, while investment decisions cannot be revised as frequently as the rate at which open market operations are carried out. See Christiano (1991) for the role of the timing assumption regarding investment in these types of models.

Generating a liquidity effect

The key feature of the basic liquidity model which allows it to generate a substantial liquidity effect is the assumed rigidity in Q_t. It is this assumption which prevents an increase in the money supply from being distributed proportionally among all agents. To see this, consider the basic cash in advance model. To keeps things simple, suppose that the growth rate of money, $x_t = X_t/M_t$, is an identically and independently distributed random variable. Under these circumstances, a positive money supply shock is neutral: it simply results in a proportional jump in current and future prices and wages, leaving all other variables unaffected. The key to this result is that the nominal expenditures of *all* agents respond to the money shock in equal proportion. Among other things, this requires that the percentage of the money stock available to financial intermediaries, $(M_t - Q_t + X_t)/(M_t + X_t)$, be invariant to X_t. But this requires that Q_t be a positive function of X_t. In the frictionless world of the basic cash in advance model this is just what happens. Knowing that the monetary authority has increased the amount of cash available to the financial sector, the representative household reacts by sending less cash to that sector and more to the consumption sector.

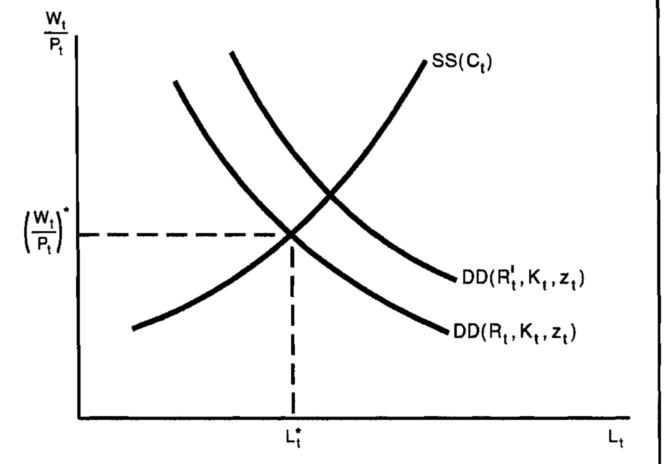
Now if Q_t does not respond to X_t, then a positive money shock increases the fraction of the money supply in the hands of financial intermediaries. As long as R_t exceeds one, financial intermediaries lend all of the cash at their disposal to firms. But this requires that firms absorb a disproportionately large share of new cash injections. For firms to do so voluntarily, interest rates must fall. Of course, if the growth rate of money displays positive persistence, then the expected inflation effects of a change in the growth rate of money exert countervailing pressure on interest rates. Under these circumstances, whether interest rates fall or rise depends on whether the liquidity effect or the expected inflation effect is stronger.

Suppose for the moment that the liquidity effect dominates, so that R_t falls in response to a positive money shock. To understand the resulting impact on aggregate employment and output, it is useful to think in terms of the demand and supply curves for labor. A necessary condition for the solution of the firm's optimization problem is that the marginal cost of an extra unit of labor equals the marginal product of that labor. Since the firm must borrow working capital at the gross interest rate R_t, this requires that $R_t W_t/P_t$ be equal to the marginal product of labor. By assumption, the marginal product of labor is a decreasing function of the amount of labor employed. So, holding the interest rate fixed, the demand for labor is a decreasing function of the real wage, W_t/P_t. This is why the demand curve for labor in Figure 1, labeled $DD(R_t,K_t,z_t)$, has a negative slope. But for a given level of W_t/P_t, the demand for labor is a decreasing function of R_t. So, in Figure 1, the demand curve labelled $DD(R_t',K_t,z_t)$, $R_t' < R_t$, lies farther from the origin than the demand curve labeled $DD(R_t, K_t,z_t)$. Finally, since the marginal product of labor is an increasing function of the stock of capital, K_t, and the level of technology, z_t, an increase in K_t or z_t also shifts the demand curve for labor away from the origin.

A necessary condition for the solution to the representative household's optimization problem is that the marginal utility of leisure equal the marginal benefit of working: W_t/P_t times the marginal utility of consumption. Conditional on a fixed value of consumption, this condition generates a static upward sloping labor supply curve that does not directly involve R_t. In Figure 1 this labor supply curve is labelled $SS(C_t)$. The equilibrium level of employment, L_t^*, and the real wage, $(W_t/P_t)^*$, corresponding t o an interest rate of R_t, is depicted by the intersection of the curves $DD(R_t,K_t,z_t)$ and $SS(C_t)$. Notice that if the monetary authority is able to drive down the interest rate, it can shift the labor demand curve to the right without inducing a directly offsetting shift in the labor supply curve. If the general equilibrium effects on consumption are small, this logic suggests that unanticipated expansionary monetary policy disturbances which drive interest rates down generate increases in aggregate hours worked and output as well as the real wage rate.

FIGURE 1

Equilibrium in the labor market



Quantitative properties of the basic liquidity model

To investigate the quantitative properties of the basic liquidity model we calculated the dynamic response of the system to a shock in the growth rate of money. For now, we suppose, as in Christiano and Eichenbaum (1992a) that the growth rate of money, x_t, evolves according to:

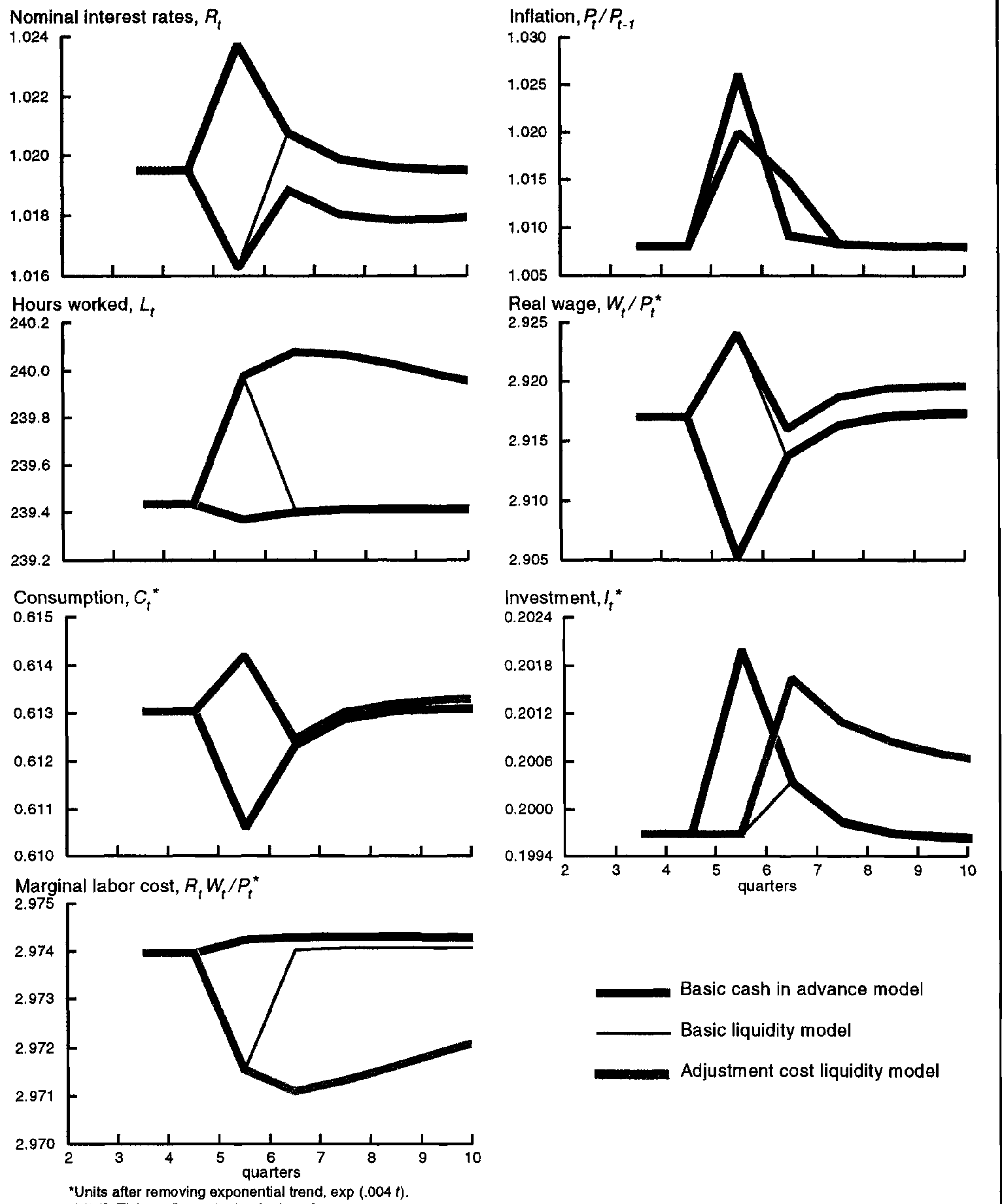
$$(7)\quad x_t = (1 - \rho_x)x + \rho_x x_{t-1} + \varepsilon_{xt}.$$

Here ε_{xt} is an independent and identically distributed random variable with standard deviation $\sigma_{\varepsilon x}$, $0 < \rho_x < 1$, and x denotes the unconditional mean of x_t. According to this specification, the growth rate of money displays positive serial persistence. The larger ρ_x is, the more serial persistence there is in x_t.

Figure 2 displays the response of the basic cash in advance and liquidity models to a one standard deviation increase in x_t due to a positive shock in ε_{xt} which occurs in period 5. All calculations are based on values for the parameters of the model equal to those used in Christiano and Eichenbaum (1992a).[2] Consider first the response of the system in the basic cash in advance model. In the impact period of the shock, the interest rate, R_t, and investment, I_t, rise, while consumption, C_t, falls. Consumption and investment respond in different ways because the rise in R_t acts like a tax on the cash good, C_t, and a subsidy on the credit good, I_t. Notice also that time worked, L_t, falls. This effect can be viewed as reflecting a leftward shift in the labor demand curve and a rightward shift in the labor supply curve. The former is induced by the rise in R_t, the latter by the fall in C_t. Both shifts contribute to a fall in the real wage, W_t/P_t. That L_t falls reflects that the shift in the labor demand curve dominates the shift in the labor supply curve. With L_t down and diminishing marginal labor productivity, the margin-

FIGURE 2

Dynamic response to money growth shock



*Units after removing exponential trend, exp (.004 t).
NOTE: Ticks indicate the beginning of quarters.

al cost of hiring labor, $R_t W_t/P_t$, must rise. Finally, since L_t has fallen and the stock of capital is unchanged, current output must also fall. With output down, and the stock of money up, prices rise by more than the percentage change in the money supply.

Since $0 < \rho_x < 1$, monetary growth continues to be high relative to its steady state level. But with the growth rate of money declining, the inflation rate also declines toward its steady state value. Consequently, R_t declines to its steady state value from above. With R_t declining, consumption slowly rises to its steady state value while investment declines to its steady state level. Since a high value of R_t depresses labor demand, as long as R_t is high, hours worked and the real wage stay low relative to their steady state values and the marginal cost of hiring labor stays high relative to its steady state value.

All in all, it seems hard to imagine a scenario more at variance with the conventional view regarding the effect of an unanticipated positive shock to the money supply.

In sharp contrast to the basic cash in advance model, the basic liquidity model implies that the contemporaneous value of R_t falls, while the corresponding values of C_t and L_t rise in response to a positive money supply shock. The rise in L_t can be thought of as occurring because the fall in R_t induces a rightward shift in the labor demand curve, while the rise in consumption induces a leftward shift in the labor supply curve. Both shifts contribute to a rise in the real wage rate, W_t/P_t. That L_t rises reflects the fact that the shift in the labor demand curve dominates the shift in the labor supply curve. With L_t up, and diminishing marginal labor productivity, the marginal cost of hiring labor, $R_t W_t/P_t$, falls. Since the stock of capital is unchanged, the rise in L_t implies that output increases, which mutes the contemporaneous rise in the price level. Consequently, the initial rise in the inflation rate is less than the initial percentage increase in the money supply. The intuition regarding the dynamic response of the system thereafter is similar to the basic cash in advance model.

We conclude that, at least at a qualitative level, the basic liquidity model seems quite promising in terms of its ability to account for the basic facts which motivate the conventional view of the effects of money supply shocks. Still, the model clearly fails on one key dimension: it cannot generate *persistent* liquidity effects. Because households face zero costs of adjusting sectoral flows of funds over different periods of time, all flows are instantly adjusted in the period after a monetary disturbance. This pattern of adjustment is reflected in Figure 4a (see below), which depicts the dynamic response of Q_t/Q_{t-1} to an unanticipated shock in the money supply. By assumption, the household cannot adjust the amount of funds it sends to the consumption sector in the impact period of the shock (period 5). Therefore, Q_t/Q_{t-1} equals its steady state value, $(1 + x)$, when $t = 5$. In the next period the household sharply increases the amount of funds sent to the consumption sector so that Q_t/Q_{t-1} exceeds $(1 + x)$. Thereafter, Q_t/Q_{t-1} quickly returns to its steady state value. To a first approximation, the only period in which firms must absorb a disproportionate amount of the money stock is period 5. And this is the only period in which there is a quantitatively significant liquidity effect.

Generating a persistent liquidity effect

One way to induce persistent liquidity effects is to modify the environment so that the financial sector remains more liquid than the consumption sector for several periods after a money supply shock. This can be done by assuming that adjusting Q_t is costly. If, because of these adjustment costs, households increase Q_t by a relatively small amount in the period after the money shock, then in that period too, financial intermediaries and firms have to absorb a disproportionately large share of the economy's funds. As long as this is true, liquidity effects persist. We show that substantial persistence effects can be generated with only very small adjustment costs.

Explicitly modeling the reasons why adjusting the growth rate of Q_t is costly is beyond the scope of this article. Here we simply adopt a convenient functional form to investigate the potential of this mechanism for generating persistent liquidity effects. Let H_t denote the amount of time agents spend on reorganizing flows of funds. We assume that H_t is given by

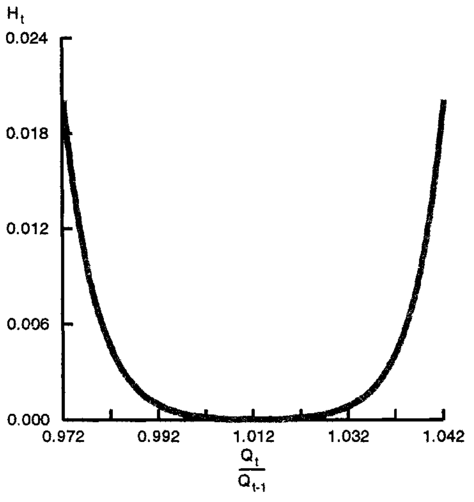
$$(8)\quad H_t = d\,T\{\exp[c(Q_t/Q_{t-1} - (1 + x))] + \exp[- c(Q_t/Q_{t-1} - (1 + x))] - 2\}.$$

Figure 3 displays this function for $c = 150$ and $d = 0.00005$. Notice that H_t is a symmetric function about $Q_t/Q_{t-1} = (1 + x)$. We refer to a modified version of the basic liquidity model in which leisure is defined by $(T - L_t - H_t)$ as the *adjustment cost liquidity model.* The steady states of the two models coincide because both the level and the derivative of H_t with respect to Q_t/Q_{t-1} are zero in steady state.

Figure 2 displays the dynamic response of this model to a one standard deviation shock in the growth rate of money. In the impact period of the shock, the system's response is identical to that of the basic liquidity model. But now, since financial intermediaries remain flush with cash, the liquidity effect persists. The financial sector remains relatively liquid be-

FIGURE 3

Adjustment cost function



cause households persist in sending it a relatively large amount of funds.

The dynamic response of R_t to a money shock is determined by the relative strength of the expected inflation and liquidity effects. In the impact period of the shock, the expected inflation effect plays no role in determining the interest rate response.[3] This is because, in the immediate aftermath of the money shock, the only participants in financial markets are firms and financial intermediaries. Neither of these agents cares about inflation when making their money market decisions. As long as the interest rate is positive, financial intermediaries lend all of their funds without regard to expected inflation. In deciding how much to borrow, firms simply equate the marginal cost of hiring labor, $R_t W_t$, with the value of the marginal product of labor, $P_t MPL_t$, where MPL_t denotes the time t marginal product of labor. This first order condition does not involve the inflation rate.

Anticipated inflation effects do play a role in the periods after a money shock. This is because, in these periods, households participate in financial markets and they do care about expected inflation when making their money market decisions. This is why the drop in R_t is smaller in the period after the shock than it is in the impact period. Given the assumed law of motion for x_t, the anticipated inflation effect rapidly dissipates after period 6. But, the liquidity effect persists until Q_t has reached its new, higher steady state growth path. This explains the kink in the impulse response function. As households slowly adjust the growth rate of Q_t, the percentage of the money stock going to the financial sector is reduced and the interest rate slowly climbs back to its steady state value. The movements in the other variables of the system mirror the movements in R_t in the way suggested by our discussion of the basic liquidity model.

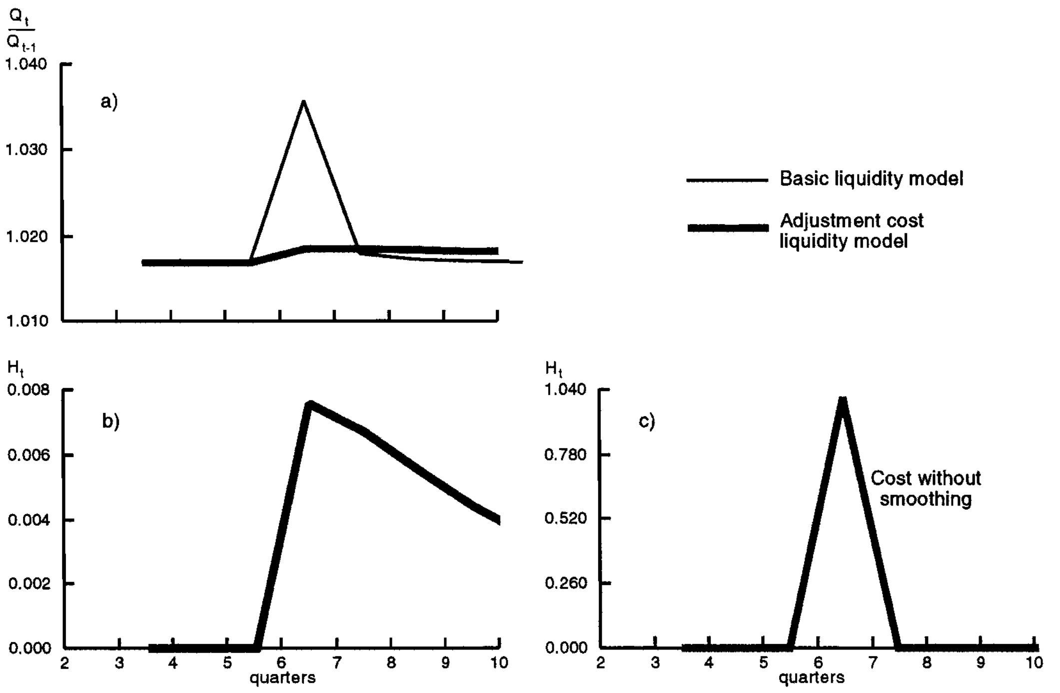
The preceding results establish that, once costs of adjusting Q_t are introduced into the analysis, money supply shocks lead to persistent liquidity effects. A key remaining question is how to assess the magnitude of the adjustment costs used in the previous example. To do this, we consider two measures. The first measure is the actual amount of time spent by the household adjusting Q_t after a shock to the money supply. From Figure 4b we see that the maximal value of H_t occurs in period 6, at .0076 of one hour, that is, 27 seconds. So, according to this metric, the adjustment costs are very small.

Our second measure is based on the following experiment. Suppose that the representative household responded to a shock in the supply of money as if there were no adjustment costs, that is, as if the parameters c and d were equal to zero. The resulting sequence of values for Q_t / Q_{t-1} would then be the same as those emerging from the basic liquidity model. We can measure the time spent on implementing these changes using (8) for $c = 150$ and $d = 0.00005$. The excess of this measure of H_t over its value in the adjustment cost liquidity model represents the time the household avoids wasting by smoothing its adjustment to a monetary shock. According to Figure 4c, H_t achieves its maximal value of one hour in the period after the shock. Thereafter, H_t is approximately zero. So, all of the persistence in the adjustment cost liquidity model is induced by the household's effort to avoid wasting two minutes a day during the quarter after the shock. Evidently, regardless of which metric we use, the adjustment costs in our example seem quite small.

We conclude that, once small adjustment costs are introduced into the analysis, our model can generate persistent declines in the interest rate following a money supply shock.

FIGURE 4

Time spent adjusting flows of funds in response to money shock



Some policy implications

In this section we discuss some of the welfare implications of our model. Given the early stage of the research program, it is premature to take detailed policy prescriptions emerging from the model literally. Still, the policy implications of the model are interesting for at least two reasons. First, they make very clear the nature of the frictions built into the model. Second, they are suggestive of the general policy principles which might emerge from future research.

Unlike the model of the previous section, actual economies are buffeted by a variety of shocks which affect agents' production opportunities and their demand for money. Holding the growth rate of money fixed in the face of these types of shocks (say, by adopting the k percent money growth rule advocated by Friedman [1968]) will not be optimal. The simplest way to show this is to modify the adjustment cost liquidity model and allow for shocks to technology. Until now, we assumed that the level of technology, z_t, grows at the constant growth rate μ. Suppose instead that the law of motion for z_t is given by:

(9) $z_t = \exp(\mu t + \theta_t)$,

where θ_t is a stationary shock to technology which evolves according to

(10) $\theta_t = \rho_\theta \theta_{t-1} + \varepsilon_{\theta t}$.

Here, $0 < \rho_\theta < 1$ and $\varepsilon_{\theta t}$ is an independently and identically distributed shock to θ_t with standard deviation $\sigma_{\varepsilon\theta}$. This specification for the shock to technology is standard in the real business cycle literature (see Hansen [1985]).

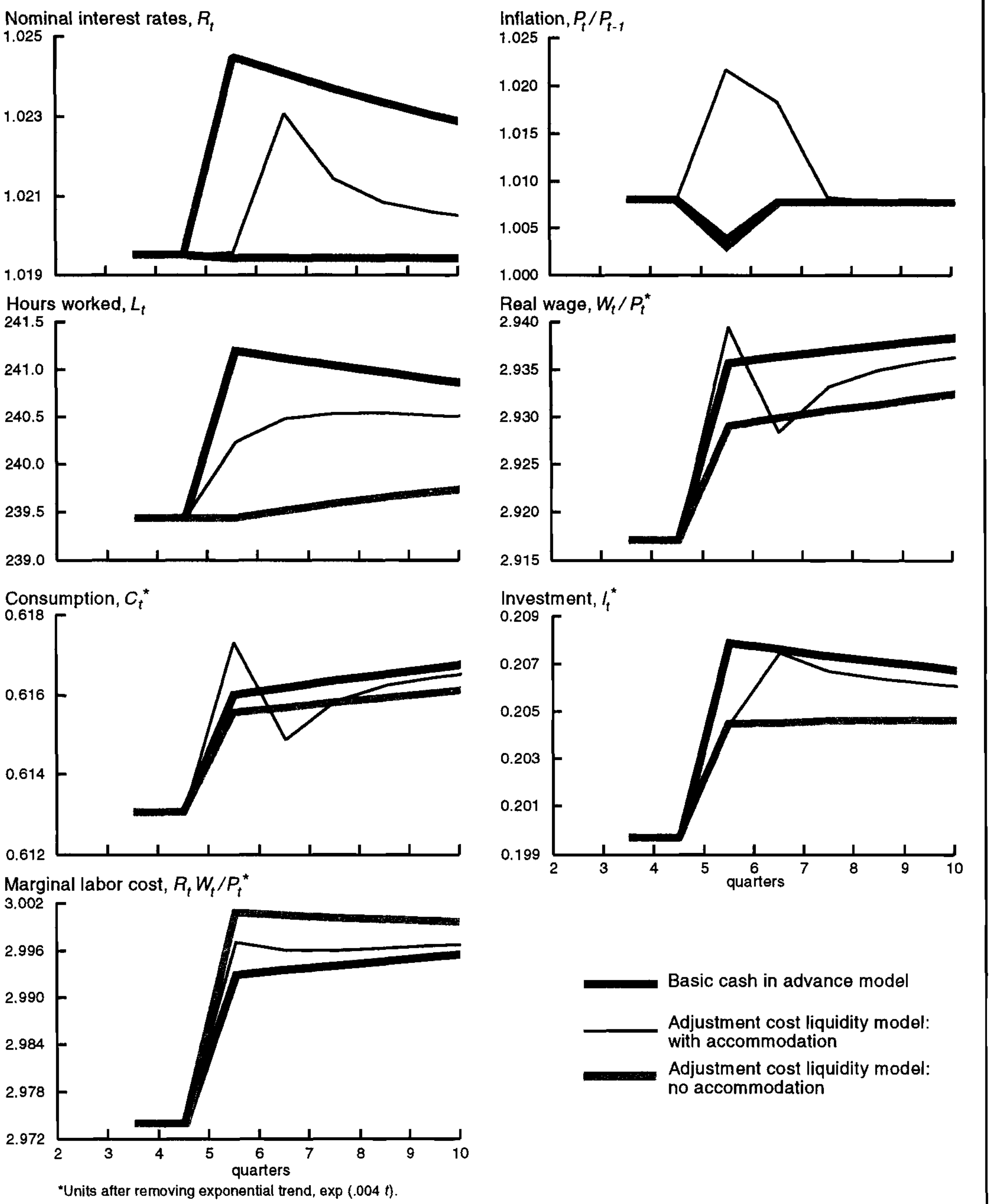
We assume that θ_t is revealed after agents choose Q_t. This assumption captures the notion that, due to a variety of unmodeled costs, households do not immediately direct cash to the financial sector when unexpected productive opportunities arise in the firm sector. As before, we assume that x_t is realized after agents choose Q_t, and that x_t evolves according to (7). Finally, we assume (as before) that firms choose I_t before observing X_t but after observing θ_t. The timing assumptions on I_t can be interpreted as reflecting the notion that, in reality, firms have advance information about changes in their own technology, but not about open market operations.

It is straightforward to prove that employment does not respond contemporaneously to a technology shock. A key factor underlying this result is that the wage bill, $W_t L_t$, is independent of the realization of θ_t. This latter result reflects the fact that the quantity of dollars supplied by financial intermediaries, $M_t - Q_t + X_t$, is by assumption independent of θ_t. This does not establish the result, however, since it leaves open the possibility that the wage rate could fall, thus permitting an increase in employment. As it turns out, our specification of preferences, (2), and the cash in advance constraint, (3), do rule out this possibility.[4]

Figure 5 displays the dynamic response of the adjustment cost model to a shock in tech-

FIGURE 5

Dynamic response to technology shock

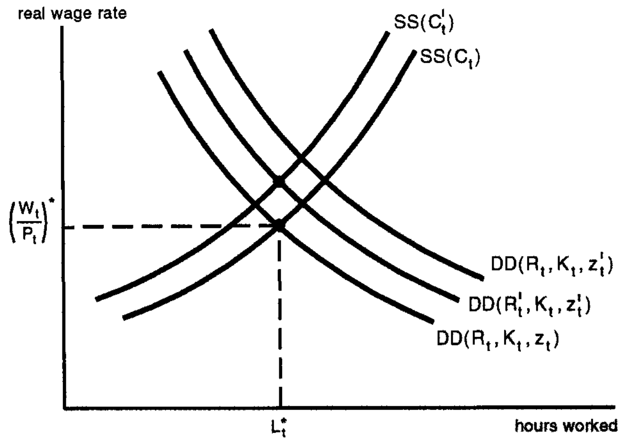


*Units after removing exponential trend, exp (.004 t).

nology that occurs in time period 5.[5] In the impact period of the shock, hours worked do not change, while consumption, investment, the real wage, the marginal cost of hiring labor, $R_t W_t/P_t$, and the nominal interest rate, R_t, all rise. To understand the interest rate response, it is useful to take as given the result that, in equilibrium, contemporaneous employment does not change. With this in mind, consider Figure 6 which depicts the demand for and the supply of labor. The initial equilibrium is given by the intersection of the demand and supply curves, $DD(R_t,K_t,z_t)$ and $SS(C_t)$, at L_t^* and $(W_t/P_t)^*$. A positive shock to θ_t increases z_t and raises the marginal product of labor. So, holding R_t fixed, the demand curve for labor shifts rightwards to the curve labeled $DD(R_t,K_t,z_t')$, where $z_t' > z_t$. Abstracting from shifts in labor supply and given that equilibrium employment cannot increase, the interest rate must increase by enough to shift the labor demand curve back to where it was before the technology shock. In practice, a positive technology shock leads to a rise in consumption which causes the labor supply schedule to shift left, thus mitigating the rise in the interest rate.[6] In Figure 6 the new supply curve of labor is given by $SS(C_t')$, where $C_t' > C_t$.

FIGURE 6

Equilibrium in the labor market: response to technology shock



In the period after the shock, Q_t begins to fall. The increased flow of funds from households to financial intermediaries permits an increase in hours worked. With L_t rising and diminishing marginal labor productivity, the marginal cost of hiring labor, $R_t W_t/P_t$, slowly declines, while the real wage, W_t/P_t, slowly rises as the system reverts to its (unchanged) steady state. As a reference point, Figure 5 also displays the dynamic response of the economy to a technology shock in the basic cash in advance model. Notice that the employment response in the cash in advance model is uniformly larger than the corresponding response in the adjustment cost liquidity model. Evidently, in the adjustment cost liquidity model, the economy does not take full advantage of the improved production opportunities.

This suggests that the representative household's welfare (1) could be enhanced if the monetary authority were to increase the money supply in response to a positive technology shock. To investigate this, we modified the law of motion for x_t to allow monetary policy to respond to shocks in technology. Specifically, we assume that x_t evolves according to

$$(11)\quad x_t = (1-\rho_x)x + \rho_x x_{t-1} + \varepsilon_{xt} + \nu\varepsilon_{\theta t}.$$

When $\nu > 0$, the monetary authority accommodates a positive technology shock by increasing the money supply.

Figure 5 displays the response of the model to a one standard deviation shock in technology when $\nu = 1.5$. Notice that with accommodative monetary policy, hours worked increase immediately in the wake of a positive technology shock. Notice also that the rise in the interest rate induced by the technology shock is muted compared to the situation in which $\nu = 0$. In this sense, accommodative monetary policy serves to smooth the interest rate. With the monetary authority increasing the supply of cash to financial intermediaries after a technology shock, there is simply less pressure on the interest rate.[7]

Conclusion

In this article, we have investigated a class of models which is capable of accounting for the conventional view that positive shocks to the money supply generate persistent decreases in short term interest rates as well as persistent increases in hours worked and output. The models are clearly at an early stage of development. Still, they serve to highlight a key friction in the actual economy which we believe is central to understanding the ability of the monetary authority to affect aggregate economic variables via open market operations. We believe that this class of models will serve as an important building block for future research into the interaction of monetary policy and aggregate economic activity.

FOOTNOTES

[1]We make capital a credit good in order to minimize the impact of inflation on average employment in the model. For a further discussion of this point, see Christiano (1991) and Stockman (1981).

[2]Specifically, the parameters β, μ, α, γ, δ, x, $\sigma_{\varepsilon x}$, and ρ_x were set equal to $(1.03)^{-.25}$, 0.004, 0.36, 0.797, 0.012, 0.012, 0.014, and 0.30, respectively. Also, $A = T^{(\alpha-1)}$, and $T = 1{,}369$. See also Christiano and Eichenbaum (1992b).

[3]In particular, Christiano and Eichenbaum (1992a), footnote 14, show that the interest rate response to a money shock is independent of the value of ρ_x.

[4]Equation (3), together with the loan market clearing condition, (i) $W_tL_t = M_t - Q_t + X_t$, imply (ii), $P_tC_t = M_t + X_t$. The unitary elasticity of substitution assumption between consumption and leisure implicit in our specification of preferences, (2), implies that the value of consumption is proportional to the value of leisure, that is, (iii) $P_tC_t = W_t(T - L_t - H_t)(1-\gamma)/\gamma$. Combining (i), (ii), and (iii), we obtain $M_t + X_t = W_t(T - H_t)(1-\gamma)/\gamma - (M_t - Q_t + X_t)(1-\gamma)/\gamma$. This equation determines W_t as a function of Q_t, M_t, and X_t. Since the latter are independent of θ_t it follows that W_t is also independent of θ_t. From (i), it is clear that if W_t is independent of θ_t, then L_t must also be independent of θ_t. This establishes our result.

[5]For ρ_θ and $\sigma_{\varepsilon\theta}$ we use the point estimates obtained by Burnside, Eichenbaum, and Rebelo (1993): $\rho_\theta = .9857$ and $\sigma_{\varepsilon\theta} = .014$.

[6]The extent to which the labor supply curve shifts to the left is minimized by our assumption that investment decisions are made after the realization of θ_t. Because I_t responds positively to θ_t, the resource constraint limits the extent to which consumption can increase after a positive technology shock.

[7]See Fuerst (1992a,b) for a related analysis of optimal monetary policy.

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