NBER WORKING PAPER SERIES

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Lawrence J. Christiano

Martin Eichenbaum

Working Paper No. 3974

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 1992

This paper is forthcoming in the 1992 *AER Papers and Proceedings*. We thank Mike Gavin, Mark Watson, and Steve Strongin for helpful conversations, Kathy Rolfe for editorial assistance, Joseph R. Piepgras for technical assistance, and the National Science Foundation for financial support. This paper is part of NBER's research programs in Economic Fluctuations and Monetary Economics. Any opinions expressed are those of the authors and not those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System or of the National Bureau of Economic Research.

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ABSTRACT

Several recent papers provide strong empirical support for the view that an expansionary monetary policy disturbance generates a persistent decrease in interest rates and a persistent increase in output and employment. Existing quantitative general equilibrium models, which allow for capital accumulation, are inconsistent with this view. There does exist a recently developed class of general equilibrium models which can rationalize the contemporaneous response of interest rates, output, and employment to a money supply shock. However, a key shortcoming of these models is that they cannot rationalize *persistent* liquidity effects. This paper discusses the basic frictions and mechanisms underlying this new class of models and investigates one avenue for generating persistence. We argue that once a simplified version of the model in Christiano and Eichenbaum (1991) is modified to allow for extremely small costs of adjusting sectoral flow of funds, positive money shocks generate long-lasting, quantitatively significant liquidity effects, as well as persistent increases in aggregate economic activity.

Lawrence J. Christiano
Research Department
Federal Reserve Bank of Minneapolis
Minneapolis, MN 55480

Martin Eichenbaum
Department of Economics
Northwestern University
Evanston, IL 60208
and NBER
and Federal Reserve Bank
of Chicago

> Experience and common sense tell us that . . . ordering materials and hiring workers . . . will look like a better deal if the prime rate is 6% instead of 8% . . . . [James Tobin, 1991, p. A14]

Conventional wisdom holds that an expansionary monetary policy shock generates a persistent decrease in nominal interest rates and a persistent increase in the level of employment and output. However, the traditional literature contains very little econometric evidence to support this view (William Reichenstein, 1987). A hallmark of this literature is its use of the identifying assumption that monetary policy disturbances correspond to the statistical innovation in measures of money like the monetary base or M1. Recently, several researchers have argued that this assumption is grossly counterfactual in light of the actual operating procedures of the Federal Reserve Board (Ben Bernanke and Alan Blinder, 1990; Lawrence J. Christiano and Martin Eichenbaum, 1991, forthcoming-b; Steven Strongin, 1991; Martin Eichenbaum, forthcoming; Christopher A. Sims, forthcoming). Each of these researchers argues that innovations to broad monetary aggregates primarily reflect shocks to money demand rather than shocks to money supply, or policy. Pursuing alternative assumptions for identifying money supply shocks, each provides strong empirical evidence in support 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. Certainly, this is true for real business cycle models in which money is introduced simply by imposing cash-in-advance constraints on agents or by incorporating a transaction demand for money. A generic implication of these models is that, if money growth displays positive persistence, then unanticipated shocks to the growth rate of money drive interest rates up, not down (Lawrence J. Christiano, 1991; Christiano and Eichenbaum, 1991). This is because, in these models, money shocks affect interest rates exclusively through an anticipated inflation effect. More surprisingly, Robert G. King (1991) and Robert G. King and Mark Watson (1991) show that the mere existence of "sticky" wages or prices per se also does not rationalize the conventional view.

In our opinion, any convincing rationalization of the conventional view will involve business cycle models in which monetary policy shocks generate significant, persistent liquidity effects. Recently, some researchers have studied general equilibrium models in which purely *transitory* liquidity effects arise (Robert E. Lucas, Jr., 1990; Christiano and Eichenbaum, 1991; Timothy S. Fuerst, forthcoming; and the references therein). Because of the strong liquidity effect in these models, a positive money shock drives the nominal interest rate down. Output then expands, in part because of the reasons suggested in the quote by Tobin (1991) at the start of this paper.

While these models cannot rationalize *persistent* liquidity effects, we view them as interesting starting points for a broader research program. This paper discusses the basic frictions and mechanisms underlying the liquidity effects in these models and investigates one way to generate persistence. We argue that once a simplified version of the model in Christiano and Eichenbaum (1991) is modified to allow for extremely small costs of adjusting sectoral flows of funds, positive monetary policy shocks generate long-lasting, quantitatively significant liquidity effects as well as persistent increases in aggregate economic activity.

I. The Economic Environment

We begin by considering a simplified version of the model in Christiano and Eichenbaum (1991) in which the only source of uncertainty in agents' environment pertains to monetary policy. The model has three types of agents: households, goods-producing firms, and financial intermediaries. At the start of period t, the representative household possesses the economy's entire beginning-of-period money stock M_t. The household allocates Q_t dollars to purchases of the consumption good, C_t, and lends the rest, $M_t - Q_t$, to financial intermediaries. Consumption purchases must be fully financed with cash that comes from two sources: Q_t and current-period wage earnings. The household chooses Q_t, C_t, and the fraction of period t devoted to work L_t to maximize the expected value of the criterion $\Sigma_{t=0}^{\infty}\beta^t U(C_t, 1-L_t)$. Here $U(C_t, 1-L_t)$ denotes the household's utility function, given by $(1-\gamma)\ln(C_t) + \gamma\ln(1-L_t)$. Also, β and γ are scalars between zero and one.

This maximization occurs by choice of contingency plans for L_t and C_t, which are functions of model variables dated period t and earlier. In the *basic liquidity model*, the household's contingency plan for Q_t is not a function of the period t realization of monetary policy. This assumption is intended to capture, in an analytically convenient way, the institutional and other factors which constrain households' choice of Q_t, at least in the short run. Institutional considerations include the fact that, in the real world, a fraction of M_t is held by firms and financial intermediaries in the form of retained earnings or pension funds and cannot readily be allocated by households to change Q_t. In addition, a variety of fixed costs, such as those stressed by George A. Akerlof (1979), render it suboptimal for households to continually readjust their nominal consumption/saving plan.

To illustrate the impact of the assumed rigidity in Q_t, we also analyze the *basic cash-in-advance* (CIA) *model*, which allows Q_t to be a function of the period t innovation in monetary policy. In both models, the maximization occurs subject to the cash constraint that nominal consumption expenditures, P_tC_t, cannot exceed Q_t plus W_tL_t. Here P_t and W_t denote the period t dollar price of goods and labor, respectively. In addition, the household must obey its budget constraint,

(1) $$M_{t+1} = R_t(M_t - Q_t) + D_t + F_t + (Q_t + W_tL_t - P_tC_t),$$

where R_t is the gross interest rate in period t and F_t and D_t denote period t dividends received from firms and financial intermediaries, respectively. This budget constraint does not reflect households' ownership of firms and financial intermediaries since we assume—without loss of generality—that shares in these entities are not traded.

The financial intermediary has two sources of funds: $M_t - Q_t$ and lump-sum injections X_t of cash by the monetary authority. 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.

The period t technology for producing new goods is given by

$$(2) \quad f(K_t, z_tL_t) = K_t^{\alpha}(z_tL_t)^{1-\alpha} + (1-\delta)K_t$$

for $0 < \alpha < 1$ and $0 < \delta < 1$. Here K_t is the beginning-of-period t stock of capital, δ is the rate of depreciation on capital, and the function $f(\cdot,\cdot)$ denotes new period t output plus the undepreciated part of capital. Also, z_t is the state of technology at period t, which grows at the constant geometric rate $\mu > 0$. Firms must borrow working capital W_tL_t from financial intermediaries to cover their labor costs. 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 $R_tW_tL_t$.

Firms own the stock of capital, which evolves according to

$$(3) \quad I_t = K_{t+1} - (1-\delta)K_t,$$

where I_t denotes period t gross investment. Unlike labor, capital is assumed to be a credit good, so that the firm need not borrow funds from the financial intermediary to finance investment activities. At the end of the period, after the consumption good market closes, the firm's net cash position is distributed to its owner, the household. The perfectly competitive firm maximizes the expected present discounted value of dividends by choice of contingency plans which specify I_t and L_t as functions of model variables dated period t and earlier.

II. Generating a Liquidity Effect

The key feature of the basic liquidity model which lets it generate a substantial liquidity effect is that the assumed rigidity in Q_t prevents an increase in the money supply from being distributed proportionally among all agents. To see this, first consider the basic CIA model. To keep things simple, suppose that the growth rate of money, X_t/M_t, is an i.i.d. random variable. Under these circumstances, a money shock is neutral: it simply results in a proportional jump in current and future prices and wages, leaving all other variables unaffected. The key feature of the basic CIA model which underlies this result is that the nominal expenditures of all agents respond to the money shock in an equiproportionate manner. 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. It is easily confirmed that this requires Q_t to be a positive function of X_t.

If Q_t does not respond to X_t, a positive money shock increases the total percentage of the money supply available to 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 which 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 in $(W_t/P_t,L_t)$ space. The firm's Euler equation for L_t equates the marginal cost of an extra unit of labor to the marginal product of that labor. Since the firm must borrow working capital at the gross interest rate R_t, this requires that R_tW_t/P_t equal the marginal product of labor. It follows that an increase in the interest rate shifts the labor demand curve toward the origin.

The household's Euler equation for labor equates the marginal utility of leisure to the marginal benefit of working, W_t/P_t, times the marginal utility of consumption. Conditional on a fixed value of the marginal utility of consumption, this Euler equation generates a static upward-sloped labor supply curve that does not directly involve R_t. So, if the monetary authority reduces R_t, it shifts the labor demand curve to the right without inducing a directly offsetting shift in the labor supply curve. If the general equilibrium effects on the marginal utility of consumption are small, this logic suggests that unanticipated expansionary monetary policy disturbances generate increases in aggregate hours worked and output as well as the real wage rate.

III. Some Quantitative Properties of the Basic Liquidity Model

To investigate the quantitative properties of the basic liquidity model, we calculated the impulse response functions of the system to a shock in the growth rate of money. As in Christiano and Eichenbaum (1991), here we suppose that M_{t+1} is equal to M_t plus X_t and

(4) $x_t = (1-\rho_x)x + \rho_x x_{t-1} + \epsilon_{xt},$

where x_t is the growth rate of money, X_t/M_t; ϵ_{xt} is an i.i.d. shock with standard deviation σ_{ϵ_x}; $0 < \rho_x < 1$; and x denotes the unconditional mean of x_t. In calculating our impulse response functions, we assumed values for the parameters equal to those used in Christiano and Eichenbaum (1991). The parameters β, μ, α, γ, δ, x, σ_x, and ρ_x were set equal to $(1.03)^{-0.25}$, 0.004, 0.36, 0.797, 0.012, 0.012, 0.014, and 0.30, respectively.

Figure 1 displays the response of the system to a one-standard-deviation (1.4 percent) shock in x_t which occurs in period 5. Consider first the basic CIA model. Notice that in the impact period of the shock, the interest rate R_t rises. At the same time, investment I_t rises while consumption C_t falls. This is because the rise in R_t acts like a tax on the cash good—consumption—and a subsidy on the credit good—investment. Notice also that the fraction of 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 rate 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. Given our assumption of diminishing marginal labor productivity, the marginal cost of hiring labor, R_tW_t/P_t, must rise since L_t falls. 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 after the shock. With the growth rate of money declining over time, the inflation rate also declines toward its steady-state value. Consequently, R_t is also high relative to its steady-state value but declining over time. Since R_t is declining, consumption slowly rises to its steady-state level, 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 and the marginal cost of hiring labor stays high.

To summarize, according to the basic CIA model, a positive money shock drives interest rates up and employment, consumption, and output down—just the opposite of the conventional view.

In sharp contrast to the basic CIA model, the basic liquidity model implies that the contemporaneous values of R_t and I_t fall while C_t and L_t rise in response to a positive money 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. That L_t initially 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_tW_t/P_t, falls. The contemporaneous increase in the price level is muted by the increase in aggregate output. As a result, the initial rise in the inflation rate is less than proportional to the initial percentage increase in the money supply. The intuition regarding the dynamic response of the system thereafter is similar to the basic CIA model.

While these results are encouraging, the basic liquidity 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, so that the liquidity effects generated by the model are purely transitory.

IV. Generating a Persistent Liquidity Effect

One way to induce persistence is to modify the environment so that the financial sector remains more liquid than the consumption sector for several periods after a money 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 will have to absorb a disproportionately large share of the economy's funds. As long as this is true, liquidity effects will persist. We show that substantial persistence effects can be generated with only very small adjustment costs.

Explicitly modeling the costs involved in adjusting Q_t is obviously not easy. Here we simply adopt a convenient functional form to investigate the potential of this mechanism for generating persistence effects. Let H_t denote the fraction of agents' time spent on reorganizing flows of funds. We assume that H_t is given by

$$(5) \quad H_t = d\{\exp[c(Q_t/Q_{t-1} - (1+x))] + \exp[-c(Q_t/Q_{t-1} - (1+x))] - 2\}.$$

In nonstochastic steady state, Q_t/Q_{t-1} is equal to $(1+x)$. So both the level of H_t and its derivative with respect to Q_t/Q_{t-1} equal zero in nonstochastic steady state. More generally, (5) implies that changing Q_t is costly, with the marginal cost being an increasing function of the parameters c and d. Our only other change is to define leisure as $1 - L_t - H_t$. We refer to the resulting model as the *adjustment cost liquidity model.*

To investigate the properties of this model, we calculated the impulse response function of the system to a one-standard-deviation shock in the growth rate of money assuming that d equals 0.00005 and c equals 1,000. (See Figure 1.) In the impact period of the shock, the system's response is identical to that of the basic liquidity model. But with adjustment costs, the liquidity effect persists for many periods. This reflects the fact that the percentage of the money stock absorbed by financial intermediaries and firms remains high for many periods after the money shock. Therefore, R_t reverts to its steady-state value from below, as households slowly adjust Q_t to its new steady-state value. Evidently, once costs of adjusting Q_t are allowed for, the model is capable of generating persistent liquidity effects.

A key question is just how large the adjustment costs must be. As it turns out the maximal value of H_t occurs in period 8, at 0.0133 percent of steady-state hours worked. To get a sense of the magnitude of this number, suppose that in nonstochastic steady state households work 320 hours, the sample average of actual hours worked in the postwar U.S. data (Christiano and Eichenbaum, forthcoming-a). Then the maximal value of H_t translates into a loss of three minutes in the third quarter after the shock. Evidently, only *very* small costs of adjusting sectoral flows of funds are needed to rationalize substantial persistent liquidity effects.

V. Directions for Future Research

The liquidity models studied in this paper have a variety of interesting empirical implications. We have begun exploring these by studying the ability of versions of these models to account for aspects of postwar U.S. time series data (Christiano, 1991; Christiano and Eichenbaum, 1991, forthcoming-b). However, these studies do not confront the central prediction of the models, namely, that a disproportionately large share of monetary injections is absorbed by firms to finance variable inputs. In joint work with Charles Evans, we are testing this prediction by using flow of funds data to see where the money actually goes after an open market operation.

We conclude by noting that the class of models discussed in this paper has a variety of interesting welfare implications which we have not yet fully explored. Consistent with results in Fuerst (forthcoming), optimal monetary policy in our models does not correspond to a k percent money rule of the type advocated by Milton Friedman (1968). This is because, in these models, the monetary authority has greater flexibility to quickly direct cash to the financial sector via open market operations than private agents have via adjustments in their nominal saving decisions. We expect that this friction leads to a type of real bills doctrine in which it is welfare-improving to increase the money supply in response to an unanticipated change in the real production opportunities facing private agents, such as technology shocks. In a modified version of our models which accommodates this source of uncertainty, positive technology shocks generate increases in the nominal interest rate (Christiano and Eichenbaum, 1991). Consequently, this sort of policy corresponds to an interest rate-smoothing rule of the type allegedly pursued by the Federal Reserve Board in different subperiods of the postwar era. Similar logic suggests that it may be welfare-improving to accommodate other types of shocks, like increases in the demand for money or the costs of financial intermediation, which would otherwise lead to increases in nominal interest rates. Versions of the models in which money is introduced via a stochastic transactions-based demand for money would let us formally investigate this conjecture.

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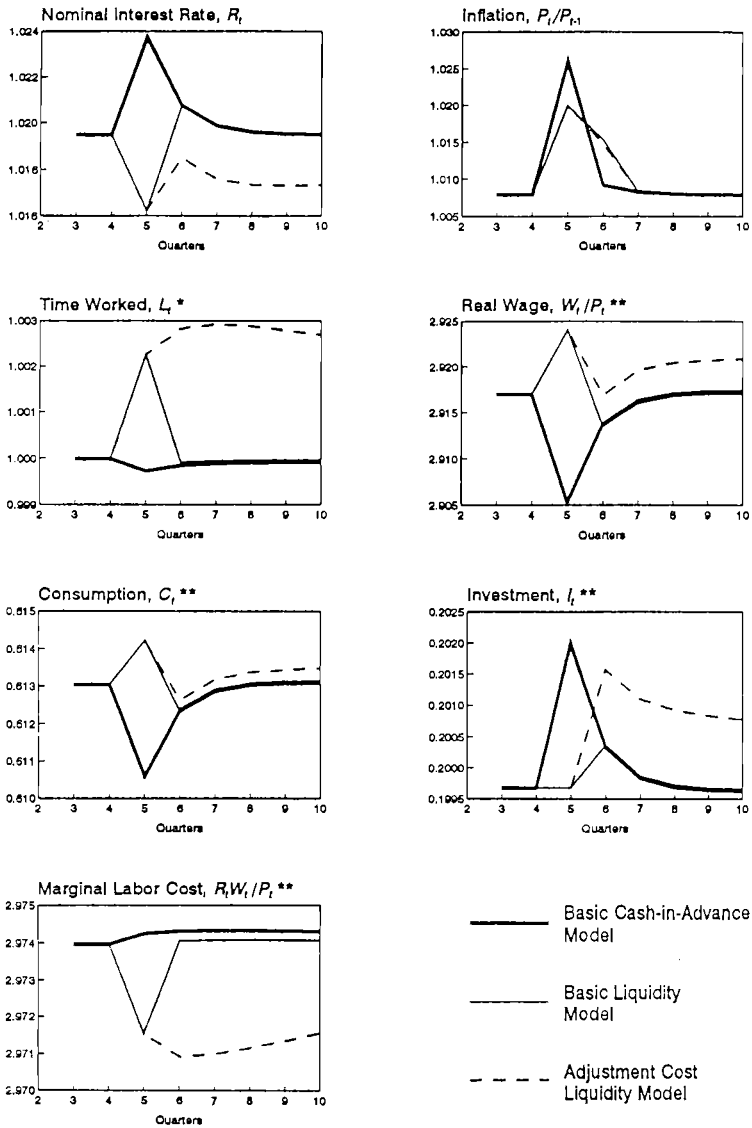
Figure 1. **Response to a 1.4% Money Growth Shock in Period 5 in Three Business Cycle Models**



* Ratio of time worked relative to nonstochastic steady-state level ($L_t/0.1749$).

** Variable after scaling by exp(-0.004t).