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This paper contains preliminary findings from research work still in progress and should not be quoted without prior approval of the authors.

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INSIDE MONEY, OUTPUT, AND CAUSALITY

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INTRODUCTION

The observed correlation between nominal money stock and real output (e.g., Friedman and Schwartz (1963a, b) and Sims (1972)) has attracted a great deal of attention among macroeconomists. The evidence, especially the precedence of money shocks to output shocks, leads one to speculate on whether the business cycle is caused by randomness in the money stock and whether deliberate changes in the fiat money stock may be used to effect changes in output.

There is however, evidence (Cagan (1965), King and Plosser (1984)) which suggests that it is primarily inside money that is correlated with output, implying that the observed nominal money shocks may represent endogenous reactions of the money stock to changes in output or to some third force causing the changes in both money and output. This view was encouraged by the work of Sims (1980) and Litterman and Weiss (1985), who showed that when interest rates were included in vector autoregressions, interest rate innovations and not those of money were found to precede the larger part of innovations in output.

Although most of the money stock is inside money and most of the money/output correlation seems related to inside money fluctuations, most attempts to explain the money/output correlations have featured fiat money as the only form of money.¹ The model of this paper looks at money/output correlations where the stock of money consists of both inside and outside money (deposits plus currency at the Federal Reserve's, M1). The model's money multiplier is endogenous, determined by the relative returns and transactions costs of inside money and fiat money. Inside money

represents deposits at banks, which use the deposits to create capital (or equivalently, to make loans to agents who create capital). It will be useful, therefore, to think of inside money as intermediated capital.

Environmental changes that make the holding of intermediated capital more attractive increase both the current money stock (through an increase in the ratio of inside to outside money) and subsequent output (through an increase in current capital). The model in many ways displays a money/output correlation like that of the data even though the changes in both money and output represent endogenous reactions to changes in some third factor. Therefore, the observed changes in the money stock are changes in the nominal stock of inside money that precede, but do not "cause", the changes in output. A change in the money stock resulting from a change in the stock of fiat money alone will not lead to any change in output.

The times series generated by the model are also consistent with the findings of Sims (1980) and Litterman and Weiss (1985) concerning nominal and real interest rates, respectively. Both nominal and real interest rates, like money, are affected by the environmental shocks before output is affected. When there are both shocks to the physical environment and the monetary base, it is the interest rate (either real or nominal), not money, that emerges as firmly Granger-causally prior to output in vector autoregressions of the interest rate, money, and output.

The remainder of this paper is organized as follows. In Section I the physical environment of the model is specified. The method by which agents can undertake intertemporal exchanges is described. Lastly the equilibrium of the model is described. Section II of the paper is used to show how exogenous disturbances can affect the time series properties of endogenous variables.

Conclusions are contained in Section III, and proofs are in Appendix A. In Appendix B we present a simulation which illustrates the models ability to mimic some of the facts described above.

I. THE MODEL

The Environment:

In each period $t \geq 1$ a continuum of two-period lived agents is born. Each agent at t acts to maximize his expected lifetime utility, given by $U(c_{1t}) + \beta_t E_t c_{2t}$, where c_{it} represents consumption by a member of generation t in the i^{th} period of life and E_t represents the expectation operator conditioned on information available at t . The value of the positive parameter β_t is known at t . The function $U(\cdot)$ is twice-continuously differentiable, increasing, and concave with $\lim_{c \rightarrow 0} U'(c) = \infty$.

In each generation there are two types of agents: "regular" agents and "prominent" agents. Each regular agent i of generation $t \geq 1$ is endowed with y_t^i units of non-storable labor. Each unit of labor is used inelastically to produce one unit of the economy's sole consumption good. There is a continuum of regular agents in each generation. The population of regular agents is normalized to equal unity. In each generation $t \geq 1$ the distribution of endowments y_t^i is described by the uniform density function $\theta(y_t^i) = 1$ for $y_0 < y_t^i \leq \bar{y}$ and $\theta(y_t^i) = 0$. The parameters y_0 and $\bar{y}$ are positive constants. The identity of a regular agent is costlessly known only to himself. Others can learn a regular agent's identity only at a fixed cost of γ units of the consumption good.

Prominent agents are costlessly identified by all. They have no endowment of labor but have access to the following capital technology to which regular agents do not have access. The number of prominent agents is sufficient to ensure a competitive equilibrium.

A unit of the consumption good at t that is not consumed may be used to create a unit of capital. A unit of capital created at t produces x_t units of the consumption good at $t + 1$. The value of x_t is a function of the aggregate amount of capital created at t (K_t): $x_t = \alpha_t X(K_t)$, where α_t is a positive constant and where $X(\cdot)$ is continuously differentiable and decreasing with $\lim_{K \rightarrow 0} X(K) = \infty$, and $[X(K) + KX'(K)] > 0$ for $K > 0$ (i.e. $X(K)K$ is increasing in K).

There exists a fixed stock of fiat money, which is intrinsically useless, unbacked, noncounterfeitable, and costless to exchange. M_t will denote the quantity of fiat money outstanding during period t . At the beginning of period 1, all fiat money is owned by the "current old", who may be considered generation 0. The current old live only in period 1 and seek only to maximize personal consumption in that period. To ensure a demand for fiat money, the government enforces (costlessly) a legal prohibition on the issue and use of privately issued bearer notes.

Media of Exchange:

The basic problem facing regular agents is how to arrange for consumption when they are not endowed. One option is to purchase fiat money from old agents to be sold for goods when the purchaser is himself old. A second option is to deposit goods with a prominent agent, who can create capital from which a return can be paid in the next period. In a competitive

equilibrium, deposits will pay the rate of return on capital. To collect this return, the regular agent must return to the prominent agent and identify himself (an action that uses up γ goods). Recall that agents are legally prohibited from purchasing notes or IOU's that are payable to the bearer.

The reader may wish to interpret a deposit of goods with a prominent agent as a deposit at a bank or some similar financial intermediary. The cost γ may then be interpreted as the cost or bother of identifying oneself in person at the bank or of identifying oneself by the writing of a check. The legal restriction may be considered a prohibition on private banknotes, like the restrictions present in most modern economies.

Equilibrium:

The problem of a regular agent born at t and endowed with y who holds only inside money (bank deposits) is to choose non-negative consumption and real balances of inside money, h_t , to maximize $U(c_{1t}) + \beta_t E_t c_{2t}$ subject to

$$y = h_t + c_{1t} \text{ and } x_t h_t - \gamma = c_{2t}. \quad (1)$$

Since the agent knows x_t and γ when he makes his decision. The (necessary and sufficient) first order condition for a maximum is:

$$-U'(y - h_t) + x_t \beta_t = 0. \quad (2)$$

The problem of a regular agent born at t and endowed with y who holds only fiat money is to choose non-negative consumption and real balances of fiat money, q_t , to maximize $U(c_{1t}) + \beta_t E_t (c_{2t})$ subject to

$$y = q_t + c_{1t} \text{ and } \rho_t q_t = c_{2t} \quad (3)$$

where ρ_t is the gross real rate of return of fiat money purchased at t . The necessary and sufficient first order condition for a maximum is:

$$-U'(y - q_t) + \beta_t E_t (\rho_t) = 0 \quad (4)$$

It remains to describe the extent of the holding of inside and outside money in equilibrium. The assumption $\lim_{K \rightarrow 0} X(K) = \infty$ guarantees that a positive amount of inside money is held in equilibrium (see Lemma 1 in the appendix). We will confine our attention to equilibria in which y_0 is sufficiently large that every agent desires to consume a positive amount in the second period of life.

The average rate of return, including transaction costs, of inside money acquired at t is $(x_t h_t - \gamma)/h_t$ or $x_t - \gamma/h_t$, where h_t denotes the real quantity of inside money balances held by an agent. Note that the rate of return on inside money is an increasing function of an individual's inside money balances. Since regular agents differ only in the size of their endowment and since desired money balances are an increasing function of the endowment, inside money is more attractive the larger an agent's endowment. Since both inside and fiat money will be held in equilibrium and there is a continuum of endowments, we can identify a borderline endowment y_t^* above which all regular agents at t hold inside money and below which all hold fiat money. This borderline endowment is defined implicitly as the endowment at which the utility of an agent choosing inside money is just equal to the utility of an agent choosing fiat money:

$$U(y_t^* - h_t(y_t^*)) + \beta(x_t h_t(y_t^*) - \gamma) = U(y_t^* - q_t(y_t^*)) + \beta E_t(\rho_t q_t(y_t^*)) \quad (5)$$

where $h_t(y_t^*)$ and $q_t(y_t^*)$ are the values of h_t and q_t that satisfy the first order conditions (2) and (4) with $y_t = y_t^*$.

A final equilibrium condition is the clearing of the market for fiat money. Define p_t as the price of a unit of the consumption good in units of fiat money. Then

$$M_t = p_t Q_t \equiv p_t \int_{y_0}^{y_t^*} q_t dy \quad (6)$$

It follows that the rate of return of fiat money is $\rho_t = p_t / p_{t+1} = Q_{t+1} / Q_t$.

The essential equilibrium conditions can be summarized as the following implicit functions:

$$F_1(K, h, Q, q, y^*) \equiv K - \int_{y^*}^{\bar{y}} h dy = 0 \quad (7)$$

$$F_2(K, h, Q, q, y^*) \equiv -U'(y-h) + \alpha X(K)\beta = 0$$

$$F_3(K, h, Q, q, y^*) \equiv Q - \int_{y_0}^{y^*} q dy = 0$$

$$F_4(K, h, Q, q, y^*) \equiv -U'(y-q) + \beta(\bar{Q}/Q) = 0$$

$$F_5(K, h, Q, q, y^*) \equiv U(y^* - h) + \beta(\alpha X(K)h - \gamma) - U(y^* - q) - \beta(\bar{Q}/Q)q = 0$$

where all variables are evaluated at the current period (although the time subscripts have been suppressed to ease the notational burden.

$\bar{Q}$ denotes the expected value of Q in the next period.

II. EQUILIBRIUM TIME SERIES

We can now describe properties of the equilibrium time series under a variety of stochastic shocks in order to compare them to the time series properties outlined in the introduction.

To compare the time series of the model to those of the real world we need to define measures of output, the money stock and interest rate. Real output at t is defined to be the sum of output at t from labor and from capital or:

$$\begin{aligned} \text{GNP}_t &\equiv \int_0^{\bar{y}} y \, dy + x_{t-1} K_{t-1} \\ &= \frac{-2}{2} \frac{y^2}{y} \Big|_0^{\bar{y}} + \alpha_{t-1} X(K_{t-1}) K_{t-1} \end{aligned} \quad (8)$$

Note that because the labor decision is trivial, output is solely a function of the previous period's capital stock. The nominal money stock at t is the sum at t of deposits of intermediaries and currency (fiat money) or:

$$\begin{aligned} \text{MS}_t &\equiv M_t + K_t p_t \\ &= M_t (1 + K_t / Q_t) \end{aligned} \quad (9)$$

from the market clearing condition for fiat money $p_t Q_t = M_t$. The real interest rate at t is $\alpha_t X(K_t)$ and the expectation at t of the rate of inflation is $E_t(Q_t / Q_{t+1})$. For a given stock of fiat money, the total nominal money stock is determined by the ratio of inside to outside money, K_t / Q_t . If shocks to real balances of fiat money are serially uncorrelated, $E_t(1/Q_{t+1})$ is a constant and expected inflation is an increasing linear function of current real balances, Q_t . From the above definitions the nominal interest rate $\alpha_t X(K_t) E_t(Q_t / Q_{t+1})$ can be constructed.

Endogenous Changes in the Money Stock

Let us first examine the time series properties of an economy where the marginal product of capital, $x_t = \alpha_t X(K_t)$ is random because the parameter α_t is a serially uncorrelated random variable, (but always positive). The main properties of such an equilibrium are summarized in Proposition 1.

Proposition 1: A positive innovation to the productivity of capital created at t causes a contemporaneous positive innovation to the capital stock (K_t) and the nominal money stock (MS_t), and a subsequent positive innovation to output (GNP_{t+1}).

The intuition underlying these results is quite simple (the actual proof is presented in Appendix A). A positive shock to the marginal product of capital makes inside money, deposits backed by capital, more desirable than usual relative to unbacked fiat money. The increase in real balances of inside money and the decrease in real balances of fiat money imply an increase in the "money multiplier" ($1 + K/Q$) and therefore an increase in the nominal money stock. Moreover, because current capital increases, next period's output will rise. Therefore, the model displays the precedence of money supply shocks to output shocks as the result of an endogenous change in the money multiplier.

It is important to note that the money stock shocks displayed by this equilibrium represent changes in inside money balances, not changes in the stock of fiat money. In this regard the equilibrium is consistent with the findings of Cagan (1965) and King and Plosser (1984) that the money/output correlation is in great part a correlation between inside money balances (or "the money multiplier") and output.

Because the shocks are serially uncorrelated, a drop in current real balances of fiat money (Q) implies that the expected rate of return on fiat money ($\bar{Q}/Q$) rises and the expected inflation rate ($Q/\bar{Q}$) falls. Because the real rate of interest rises, and the expected inflation rate falls, the effect of a positive shock to α on the nominal interest rate is ambiguous. Therefore, although shocks to the productivity of capital are able to account for the money/output correlations observed by Sims (1972) and may also account for the positive correlations between the nominal interest rate and output, it does not account for the negative correlation between output and the real interest rates as measured by Litterman and Weiss (1985). A simulation of the model which uses shocks to the marginal product is described, along with the simulation technique, in Appendix B.

Now let us study the model's time series when there are serially uncorrelated fluctuations in the transaction cost γ .

Proposition 2: A negative innovation in the transaction cost (γ) faced by the generation born at t causes an increase in the capital created at t (K_t), the nominal money stock at t (MS_t), and output at $t+1$ (GNP_{t+1}), while causing decreases in the real and nominal interest rates at t as well as the expected inflation rate $E_t(Q_t/Q_{t+1})$. (Proof in Appendix A).

The effects of shocks to the transaction cost follow from the resulting change in the relative desirability of inside and outside money. A drop in the cost of using inside money increases its attractiveness relative to fiat money, increasing real balances of inside money and reducing real balances of outside money. Together they imply an increase in the nominal money supply.

The increase in inside money represents an increase in capital, which causes both the increase in subsequent output and the reduction in the real interest rate.

The decrease in real balances of fiat money implies an increase in the price level and decreases in expected inflation as well as the nominal interest rate. Therefore, a positive innovation to the transaction cost parameter unambiguously accounts for the interest rate correlations as presented by Litterman and Weiss (1985).

Finally, let us examine the effects of a shock to the demand for all money balances in the form of a shock to β .

Proposition 3: In an economy where β_t is a serially uncorrelated random variable, innovations in β_t are positively correlated with innovations in the level of real deposits (capital) at t , negatively correlated with changes in the real interest rate at t , and positively correlated with changes in output in the subsequent period.

The proof of Proposition 3 is contained in Appendix A but we will outline here the equilibrium forces leading to these results. A positive shock to β_t means that agents will wish to consume more in the second period of their lives. As a result they hold greater balances of money and a larger fraction of the population will wish to use inside rather than outside money. The real stock of inside money will therefore increase both because those using inside money hold more money and because fewer agents choose to use fiat money. The effect of the shock on the real stock of fiat money, however, is ambiguous since fewer agents choose fiat money but those who do hold more.

The increased use of deposits results in a greater current capital stock, which lowers the current real rate of interest (since $X'(K) < 0$) and raises real output in the subsequent period.

The effects of the shock on the current total nominal money stock depend on what happens to the ratio K_t/Q_t (as can be seen in (9)). If real balances of fiat money fall, the total nominal money stock rises. If not, the nominal money stock will still rise if the percentage increase in real balances of fiat money is less than that of deposits. If real balances of fiat money fall, the current price level rises and expected inflation falls. As a result the nominal interest rate also falls.

In the case that real balances of fiat money fall, the time series of this economy display properties listed in the introduction and found in postwar data by Sims and Litterman and Weiss: vector autoregressions (VAR's) involving only money and output will display a precedence of money stock shocks to output shocks. If real or nominal interest rates are included in the VAR, shocks to them will also be seen to precede output. In addition, the model displays negative correlations between the real interest rate and the money stock and between the real interest rate and future output, all of which is found in the data studied by Litterman and Weiss.

Changes in the Monetary Base

All of the monetary fluctuations described above resulted from fluctuations in the money multiplier. Those who take seriously monetary aggregates like M1 and M2 believe that the correlation between such measures and output must be essentially the same whether the money stock fluctuations

result from changes in the money multiplier or in the monetary base. Let us therefore examine the time series properties of this model when the monetary base is random.

Let us first suppose that the monetary base (M_t) changes according to the rule $M_t = z_t M_{t-1}$ ($t \geq 1$) where z_t (≥ 1) is a serially uncorrelated random which is also independent of all other exogenous disturbances. The realization of z_t is not known before t ; more precisely, $E_{t-i} z_t = \bar{z}$, a constant greater than one for $i > 0$. Assume that any expansion of the fiat money stock ($z_t > 1$) is used to finance government purchases of the consumption good, which are disposed of in a way that does not affect the utility of any agent.

Proposition 4: Output is entirely uncorrelated with serially uncorrelated shocks to the monetary base such that $E_{t-i} z_t = \bar{z}$ for $i > 0$.

The intuition underlying Proposition 4 is sufficiently obvious that no formal proof will be presented. Simply note that the attractiveness of fiat money depends on its expected rate of return, which is a function of the expected future rate of fiat money creation ($\bar{z}$) but not the current realization of the fiat money stock. Since the future money supply growth rate is unrelated to any shocks to the current fiat money stock, the real values of the current money decisions (K_t and Q_t) as well as output and investment will be unaffected by the current nominal fiat money stock.

In Propositions 1, 2 and 3 we examined a variety of possible causes for both interest rates and the money stock to precede output. They did not explain, however, why it is that when either the real or nominal interest rate

and the money stock are included with output in a vector autoregression, it is primarily innovations in the interest rate, not the money stock, that are observed to precede innovations in output. The results of Proposition 4 may help to explain why this may be so.

Consider an economy with both shocks to one of the real parameters α , β , or γ and independent shocks to z . Output and the interest rate will change only when there is a shock to a real parameter, but the money stock will change both when there is a shock to a real parameter (changing the money multiplier) and when there is a shock to the monetary base. There will be a strong correlation between the interest rate and output since each changes only when the other changes and a weaker one between money and output because there are changes in the money stock that are not linked to changes in output. Therefore, in a VAR with only money and output, money innovations will be important for predicting output; but if the interest rate is included in the VAR the money stock will lose some of its importance in the regression. This notion is illustrated in Appendix B which contains a simulation of an economy in which there exists both nominal and real shocks.

This neutrality of the monetary base is not obtained when the rate of fiat money creation is known in advance. To see this, let us maintain all our previous assumptions except to let $E_{t-1} z_t = z_t$ and $E_{t-i} z_t = \bar{z}$ for $i > 1$. The time series properties of such an economy are presented in the following proposition.

Proposition 5: An anticipated positive shock to next period's rate of fiat money creation causes an increase in the current capital stock, the current nominal money stock, and subsequent output and a decrease in the current real interest rate. (Proof in Appendix A).

Again, the intuition underlying this result is simple. An increase in the expected rate of fiat money creation lowers the expected rate of return on fiat money. Some agents therefore switch from fiat money to inside money, increasing the money multiplier (even before the base is expanded) and the stock of intermediated capital. The increased capital leads to a lower current real interest rate and greater output next period. The effect on the nominal interest rate is ambiguous because the real interest rate declines while expected inflation is rising.

Proposition 5 also suggests how it may be that an increase in the current monetary base may precede an increase in output. If the rate of fiat money creation is positively serially correlated, an innovation in the current monetary base will signal an increased likelihood of inflation next period as well, thereby encouraging some agents to switch to inside money, which reduces the current real interest rate and increases subsequent output. Although triggered by the observed shock to the monetary base, the direct cause of these effects is a change in the public's preference for inside money. In this way the model suggests a mechanism through which changes in the monetary base may affect output.

Stabilization of the Money Stock

A common interpretation (which we label "monetarism") of the money/output correlation is that fluctuations in the money stock contribute to fluctuations in output in the sense that if the money stock fluctuations were eliminated, output fluctuations would be reduced or eliminated [e.g. Friedman (1968)]. The monetarist policy in the face of output fluctuations is therefore to compensate for any changes in the money multiplier with changes

in the monetary base. In the model presented here, the monetarist policy will not reduce output fluctuations. Recall, for example, the effects of a positive shock to α . The higher rate of return on intermediated capital makes inside money more desirable, increasing the money multiplier, and encourages the holding of capital, raising future output. The total nominal money stock can be held constant in this situation only if the current stock of fiat money declines. However, a decline in the current monetary base does nothing to alter any choice problem in real terms and so fails to affect such endogenous variables as capital and output. Therefore, any real fluctuations caused by the shock to α (or any other environmental parameter) will be undampened by changes in the monetary base.²

Remarks on the Environment

The key feature of this economy is that there exists inside money backed by capital. When a change in the economy encourages agents to switch from fiat to inside money, there is an increase in the total nominal money stock and in the extent of capital-holding, which increases subsequent output.

So long as some part of inside money is backed by capital, a variety of environments will display this endogenous correlation between money and output. For example, abandoning the simplifying assumption that all capital is in the form of inside money would not change the results. Imagine that there exist separate demands for both nonintermediated capital and intermediated capital (inside money). The simplest way to do this in the context of the model presented is to assume that prominent agents, who do not need to use intermediaries to hold capital, have endowments of their own,

some of which they use to create capital. In such an economy, environmental changes that make all capital more desirable (such as an increase in α or β) will increase holdings of both intermediated and unintermediated capital, increasing subsequent output, and the current nominal money stock.

Other features of the model were also chosen so that the equilibrium can be clearly described but are not essential to the model's conclusions. For example, the cause of the illiquidity of capital is not important so long as some form of intermediation will allow it to serve as backing for deposits. The finite lifespan is also not an essential assumption. A version of the model featuring infinitely lived but spatially separated agents as in Townsend (1980) would yield the same money/output correlations so long as both inside and outside money were used as money. Indeed the source of the demand for money is not crucial. Models with money balances in the utility function or models where the advance acquisition of money is required for all transactions will have similar implications so long as some of what is defined to be money is intermediated capital.³ The money/output correlation comes from changes in the composition of money balances, not the level of the balances nor from why those balances are held.

III. CONCLUSIONS

The preceding analysis emphasizes that the statistical causality tests, as used in Sims (1972), may yield deceiving results. The finding that "money" is Granger-causally prior for aggregate output does not necessarily imply that policy-induced changes in the money supply will significantly influence future output. There may be components of the money stock that are not under the direct control of the policymaker, but which account for the correlation

between the money supply and future changes in the level of output. The model, like the work of Sargent and Wallace (1982), highlights the idea, which is becoming pervasive in the literature, that inside and outside money should not be aggregated. These variables are determined by different factors and exhibit different correlations with other endogenous aggregates. Aggregation of these variables is misleading inasmuch as it presumes that both factors exhibit the same correlations with other aggregates.

APPENDIX A

Lemma 1: In an equilibrium with valued fiat money ($Q > 0$), $X(K) > \bar{Q}/Q$ and $K > 0$.

Proof: It cannot be that $X(K) \leq \bar{Q}/Q$. There is a transaction cost γ attached to the use of inside money. Therefore, if $X(K) \leq \bar{Q}/Q$ the rate of return of fiat money would dominate that of inside money for every agent, implying that $K = 0$. But $X(0) = \infty$, which is greater than $\bar{Q}/Q$, which must be finite since $Q > 0$ and $\bar{Q}$ can be no greater than the finite total endowment of goods.

Lemma 2: In equilibrium, $h^* > q^*$.

Proof: From Lemma 1, $x > \bar{Q}/Q$. From F_2 and F_4 , $x = U'(y^* - h^*)$ and

$\bar{Q}/Q = U'(y^* - q^*)$. Therefore, $U'(y^* - h^*) > U'(y^* - q^*)$, implying that

$h^* > q^*$.

Q.E.D.

Lemma 3: The Jacobian of the equilibrium conditions (7) is positive.

Proof: The Jacobian of (7), which will be denoted D , is:

1	$y^* - \bar{y}$	0	0	h^*
$x'\beta U'$	U''	0	0	0
0	0	1	$-y^*$	$-q^*$
0	0	$-\beta Q/Q^2$	U''	0
$x'\beta h^*$	0	$\beta q^* \bar{Q}/Q^2$	0	D_{55}

Note that the above expression makes use of the first order conditions to determine that

$$\frac{\partial F_5}{\partial h} = -U'(y^* - h^*) + \beta x = 0$$

$$\frac{\partial F_5}{\partial q} = -U'(y^* - q^*) + \beta \frac{\bar{Q}}{Q} = 0$$

Moreover,

$$\frac{\partial F_5}{\partial y^*} \equiv D_{55}^* = U'(y^* - h^*) - U'(y^* - q^*) > 0$$

since $h^* > q^*$ (see Lemma 2).

From cofactor expansion we can find that

$$D = x'\beta U'(\bar{y} - y^*)A + U''A - U''x'\beta(h^*)^2 [U'' - y^* \beta Q/Q^2]$$

$$\text{where } A \equiv U''q^* \beta q^* \bar{Q}/Q^2 + \frac{\partial F_5}{\partial y^*} [U'' - y^* \beta Q/Q^2]$$

When the signs of all the terms are evaluated, $A < 0$ and $D > 0$. Q.E.D.

Proof of Proposition 1:

$$\frac{\partial K}{\partial \alpha} = \frac{-1}{D} \left| \begin{array}{ccccc} 0 & y^* - y^- & 0 & 0 & h^* \\ \beta X & U''(y-h) & 0 & 0 & 0 \\ 0 & 0 & 1 & -y^* & -q^* \\ 0 & 0 & -\beta Q/Q^2 & U''(y-q) & 0 \\ \beta X h^* & 0 & \beta Q q^*/Q^2 & 0 & D \end{array} \right|_{55}$$

$$= \frac{1}{D} X \beta (y^* - y^-) A + \frac{1}{D} U''(y-h) \beta X (h^*)^2 [U''(y-q) - y^* \beta Q/Q^2] > 0$$

because $A < 0$ and $D > 0$ (from Lemma 3).

$$\text{Recall that } GNP'_t \equiv GNP_{t+1} = \left(\frac{y^{*-2} - y_o^2}{2} \right) + \alpha X(K_t) \cdot K_t.$$

$$\therefore \frac{\partial GNP'}{\partial \alpha} = X(K)K + \frac{\partial K}{\partial \alpha} \alpha [X(K) + KX'(K)] > 0 \text{ because } X(K) + KX'(K) > 0 \text{ by}$$

assumption.

$$\frac{\partial Q}{\partial \alpha} = \frac{-1}{D} \left| \begin{array}{ccccc} 1 & y^* - y^- & 0 & 0 & h^* \\ \beta \alpha X' & U''(y-h) & X\beta & 0 & 0 \\ 0 & 0 & 0 & -y^* & -q^* \\ 0 & 0 & 0 & U''(y-q) & 0 \\ \beta \alpha X' h^* & 0 & X\beta h^* & 0 & D \end{array} \right|_{55}$$

$$= \frac{-1}{D} U''(y-q) q^2 [\alpha \beta^* \alpha X' h^* (y^* - y) + \alpha \beta h^* [U''(y-q) - (y^* - y) \beta \alpha X']]$$

$$= -\frac{1}{D} (U''(y-q)) q^2 \alpha \beta h^* < 0.$$

Since $\frac{\partial Q}{\partial \alpha} < 0$ and $\frac{\partial K}{\partial \alpha} > 0$, it must be that $\frac{\partial(MS)}{\partial \alpha} > 0$ (from (9)).

Q.E.D.

Proof of Proposition 2:

$$\frac{\partial K}{\partial \gamma} = \frac{-1}{D} \begin{vmatrix} 0 & y^* - y & 0 & 0 & h^* \\ 0 & U''(y-h) & 0 & 0 & 0 \\ 0 & 0 & 1 & -y^* & -q^* \\ 0 & 0 & -\beta Q/Q^2 & U''(y-q) & 0 \\ -\beta & 0 & \beta Q q^* / Q^2 & 0 & D_{55} \end{vmatrix}$$

$$= -\frac{\beta}{D} U''(y-h) h^* [U''(y-q) - y^* \beta Q/Q^2] < 0$$

$$\frac{\partial Q}{\partial \gamma} = \frac{-1}{D} \begin{vmatrix} 1 & y^* - y & 0 & 0 & h^* \\ \beta X' & U''(y-h) & 0 & 0 & 0 \\ 0 & 0 & 0 & -y^* & -q^* \\ 0 & 0 & 0 & U''(y-q) & 0 \\ \beta X' h^* & 0 & -\beta & 0 & D_{55} \end{vmatrix}$$

$$= \frac{\beta}{D} U''(y-q)q^* [U''(y-h) - \beta X'(y^* - y)] > 0$$

The effects on output and the nominal money stock, and the other variables easily follow (see the proof of Proposition 1).

Proof of Proposition 3:

For convenience we set $\alpha = 1$. Using the implicit function theorem, we find that

$\frac{\partial K}{\partial \beta} = \frac{-1}{D}$	0	$y^* - y$	0	0	h^*
	XU'	U''	0	0	0
	0	0	1	$-y^*$	$-q^*$
	$\bar{Q}/Q$	0	$-\beta \bar{Q}/Q^2$	U''	0
	$\frac{\partial F_5}{\partial \beta}$	0	$\beta q^* \bar{Q}/Q^2$	0	D_{55}

or

$$\frac{\partial K}{\partial \beta} = XU'(y^* - y)A/D + \frac{\partial F_5}{\partial \beta} h^* (U'')^2 / D$$

$$- U''y^* h^* [(\bar{Q}/Q)(\beta q^* \bar{Q}/Q^2) - \frac{\partial F_5}{\partial \beta} \beta \bar{Q}/Q^2] / D,$$

where $\frac{\partial F_5}{\partial \beta} = U(Xh^* - \gamma) - q \frac{Q^*}{Q}$. Since $h^* > q^*$ implies $U(y^* - h^*) < U(y^* - q)$ equation (5) implies $U(Xh^* - \gamma) > q \frac{Q^*}{Q}$. Since $U(y^* - h^*) < U(y^* - q)$ for $h^* > q^*$, $\frac{\partial F_5}{\partial \beta} > 0$ for equation F_5 to hold.

When the signs of the terms (including A and D calculated in Lemma 3) are evaluated, it can be seen that $\frac{\partial K}{\partial \beta} > 0$, i.e., a positive shock to β leads to a positive shock in current capital. A larger capital stock implies a lower real interest rate (because $X'(K) < 0$) and greater output one period later (from (8) and $X(K) > -X'(K)K$). Q.E.D.

Proof of Proposition 5

Market clearing implies $M_t = p_t Q_t$. It follows that $\rho_t =$

$$\frac{p_t}{p_{t+1}} = \frac{M_t/Q_t}{M_{t+1}/Q_{t+1}} = Q_{t+1}/Q_t z_{t+1}. \text{ Therefore, the equilibrium conditions}$$

F_4 and F_5 must be modified to read:

$$F_4(K, h, Q, q, y^*) \equiv -U'(y - q) + \beta(\bar{Q}'/Qz) = 0$$

$$F_5(K, h, Q, q, y^*) \equiv U(y - h) + \beta(X(k)h - \gamma) - U(y - q) - \beta(\bar{Q}/Qz)q = 0$$

where z represents next period's (known) rate of fiat money creation. Then

$$\frac{\partial K}{\partial z} = \frac{-1}{D} \begin{vmatrix} 0 & y^* - \bar{y} & 0 & 0 & h^* \\ \beta x & U''(y-h) & 0 & 0 & 0 \\ 0 & 0 & 1 & -y^* & -q^* \\ -\beta Q/Qz^2 & 0 & -\beta Q/Q^2 & U''(y-q) & 0 \\ \beta q Q/Qz^2 & 0 & -\beta q Q/Q^2 & 0 & U'(y^*-h) - U'(y^*-q) \end{vmatrix}$$

$$= -(1/D) U''(y-h) h^* (\beta q Q/Qz^2) (\beta Q q/Q^2) > 0$$

By similar calculations it can be established that $\partial Q/\partial z < 0$. Q.E.D.

APPENDIX B

In this appendix we construct a simulation of the model used in the paper. The stochastic driving variable for this economy will be shocks to the marginal product of capital (α_t) and to the supply of fiat currency (z_t). Ideally, a stochastic process for $\{\alpha_t, z_t\}$ would be specified in such a manner as to permit agents to construct expectations of functions of future values of (α_t, z_t) . This procedure, however, becomes problematic for the purpose of simulating the model as there are difficulties introduced through equation (5). Agents will forecast the future value of real fiat money holdings (Q_{t+1}), as can be seen from equation (7). However, the mapping from the stochastic process governing $\{\alpha_t, z_t\}$ to the process governing $\{Q_t\}$ is nontrivial. Instead we follow a procedure similar to that outlined by Sims (1984) in deriving a stochastic process for α_t which is consistent with a specific distribution for the endogenous variables.

To this end we let the values of Q_t be i.i.d. uniformly in the interval $[\frac{1}{2}, 2]$. Therefore $E(Q) = 1.25$. It is easily seen that this implies that the rate of return on money lies in the interval $[\frac{1}{2}, 1.5]$. Let $U(c) = \ln(c)$ and $X(K) = K^{-\frac{1}{2}}$. By picking $y_0 = 3$ and $\bar{y} = 10$ it can be shown that all agents' saving is positive. Substituting the solution for $q(y)$ into the equation

$$Q = \int_{y_0}^{y^*} q(y) dy$$

yields the equilibrium condition for outside money. For each value of $Q \in [\frac{1}{2}, 2]$ it can be shown that this equation yields a unique value of y^* determined by

$$y^* = .8Q + [.64Q^2 + 9 - 2.8Q]^{\frac{1}{2}}.$$

It can be then be shown that $y^* \in [3.185, 4.042]$.

The aggregate fiat money supply, set equal to unity in the initial period, is augmented each period. The government increases the supply of currency in order to increase its own consumption. Let $z_t = (M_t/M_{t-1})$. It is assumed that z_t is a random variable distributed uniformly over the interval $[1, 1.05]$. If M_t and Q_t denote the actual nominal and real quantities, respectively, of fiat currency, then the price level is determined as $P_t = (M_t/Q_t)$. For a single realization of Q , the expected rate of return on fiat money as well as y^* are determined, so that equation (5) becomes a single (implicit) equation in the single unknown x_t . Since K_t is determined by

$$K_t = \int_{y_t}^{\bar{y}} h(y) dy.$$

Hence α_t is determined as

$$\alpha_t = x_t K_t^{\frac{1}{2}}$$

190 observations were generated with this technique. Variance decompositions for aggregate output have been computed for both a two and three variable system, and the results are presented in Tables 1 and 2. Table 1 shows that the aggregate money stock can account for up to 28% of the variability in aggregate output at a forecast horizon of 20 periods, in a two variable autoregressive system. Table 2 then shows that if the nominal interest rate is added to this system, the variability of output which is

attributable to movements in the aggregate money stock falls to 3%! The nominal interest rate then accounts for 86% of the variability in output at a forecast horizon of 20 periods.

The inside money component of the money stock is that part which is useful in predicting output. The outside money stock, which is subject to random shocks, is not useful in predicting output. Hence the aggregate money stock is somewhat useful in predicting output. However, the nominal interest rate, which is strongly positively correlated with inside money, can account for a substantial portion of the variability in output.

TABLE 1

Decomposition of Variance of Output at Various Forecast Horizons

<u>Period</u>	<u>By Innovations in</u>	
	<u>M</u>	<u>O</u>
2	24	76
4	26	74
20	28	72

M = Total Nominal Money Stock; O = Aggregate Output

TABLE 2

Decomposition of Variance of Output at Various Forecast Horizons

<u>Period</u>	<u>By Innovations in</u>		
	<u>M</u>	<u>R</u>	<u>O</u>
2	0	90	10
4	1	88	10
20	3	86	10

R = Nominal Interest Rate

FOOTNOTES

¹For example, Tobin (1970) and Sims (1980) suggest that the monetary authority may be changing the monetary base in response to economic fluctuations. Lucas (1972) suggests that the surprise increases in the monetary base cause price increases that fool agents into increasing output through the mistaken belief that there is a greater real demand for their product. Models which look at inside money as the source of the monetary fluctuations are King and Plosser (1984), Lacker (1986), and Freeman (1986).

²This strong neutrality depends in part on agents' risk neutrality towards consumption when old. A policy of stabilizing the total nominal money stock will act to reduce the randomness of the price level. Therefore, if agents are risk-averse in consumption when old, fiat money is more desirable because it is a safer asset if the money stock is stabilized. This results in lower levels of capital and output in every period. However, output is still random and uncorrelated with changes in the monetary base.

³To see this note that the equilibrium conditions representing the demand for money are F_2 and F_4 of (7). Their essential properties are that an individual's demand for real balances of either form of money is increasing in both his endowment and the rate of return on money. Therefore, other money demand functions with these properties could easily be substituted. The essence of the model's money/output correlations come from condition F_5 , which determines the relative use of inside and outside money.

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