Discussion Paper 23

Institute for Empirical Macroeconomics
Federal Reserve Bank of Minneapolis
250 Marquette Avenue
Minneapolis, Minnesota 55480

December 1989

THE ROLE OF MONEY IN A BUSINESS CYCLE MODEL

Finn E. Kydland
Institute for Empirical Macroeconomics
and Carnegie-Mellon University

ABSTRACT

Two mechanisms are considered through which money can play a role in a real business cycle model. One is in the form of aggregate price surprises when there is heterogeneity across individuals or groups of individuals ("islands"). These shocks affect the accuracy of information about real compensation that can be extracted from observed wage rates. Another, perhaps complementary, mechanism is that the amount of desired liquidity services varies over the cycle due to a trade-off between real money and leisure. This mechanism leads to price fluctuations even when the nominal money stock does not fluctuate. As is the case for the U.S. economy over the postwar period, the price level is then countercyclical. A key finding is that with neither mechanism do nominal shocks account for more than a small amount of variability in real output and in hours worked. Indeed, output variability may very well be lower the larger the variance of price surprises is.

This material is based on work supported by the National Science Foundation under Grant No. SES-8722451. The Government has certain rights to this material.

1. Introduction

In the past decade or two, increasingly the language of dynamic general equilibrium theory has been used for discussing the role of monetary shocks or price shocks for business cycles. Most models of that type use imperfect information about the shocks as a way of generating real effects. In particular, imperfect information has the implication that people initially react to price shocks as though they were real changes. The early papers (Lucas 1972, 1975 and carried further by Barro 1976 and others) are mainly concerned with demonstrating the theoretical possibility of real effects resulting from nominal shocks. For that purpose, it was not essential to go into much detail about propagation that can be attributed to features of preferences and technology.

Of more recent origin is research aimed at investigating the idea that technological shocks may account for a substantial fraction of postwar business cycles (see Kydland and Prescott 1980, 1982, and Long and Plosser 1983). In these models, real propagation mechanisms are important for understanding quarterly fluctuations. Examples of model elements that have been used are multiperiod investment technology, intertemporally nonseparable utility in leisure, and the interaction of many sectors. To the extent that such mechanisms are found to be important in accounting for aggregate fluctuations, they are also of considerable interest to the monetary theorist. Combining monetary features with an explicit specification of preferences (or home production) and technology, whose parameter values can be measured or inferred with relatively little error, offers the potential for obtaining a good estimate of the additional role of nominal shocks, over and above that of technology shocks, for cyclical fluctuations.

Introducing the choice of money holdings as an explicit part of individuals' optimizing behavior has the advantage of making it possible to consider fluctuations of nominal variables, such as money stock, velocity, and the price level, and their comovements with real aggregates over the business cycle. A mechanism considered in this paper is that there is a trade-off between a household's quantity of real money and leisure (saving trips to the bank, shopping time, etc.). This is of particular interest in this model environment in view of the importance of intertemporal substitution of leisure as a real propagation mechanism for shocks.

Another mechanism, in the spirit of Lucas, operates through heterogeneity across individuals or groups of individuals (sectors). Suppose the economy consists of many "islands" that are separated in some sense. Each island experiences a productivity shock which determines its real wage, but only the nominal wage rate, say, can be observed before deciding how many hours to work in that period. Aggregate price shocks will then have real effects whose quantitative importance is investigated here.

In Table 1, some descriptive statistics for the postwar U.S. economy are presented. The log of each time series is decomposed into a trend and a cyclical component using the method described in Hodrick and Prescott (1980) and first used in a model environment in Kydland and Prescott (1982). For example, Figure 1 shows the shape of the trend in the case of real GNP. The statistics in Table 1 are computed using the cyclical components, defined as the deviations of actual values from trend, of each variable. Real GNP is plotted versus nominal M1 in Figure 2 and versus the CPI in Figure 3.

All monetary aggregates are procyclical, monetary base with a slight lag, M1 fairly contemporaneous (except for the last five years), and M2 with a slight lead. Velocity is procyclical and highly variable, while both measures of the price level are countercyclical. In view of the latter fact, it is not surprising that, whereas the relative standard deviation of cyclical real GNP was 1.7 percent as shown in Table 1, that of nominal GNP was only 1.5 percent.

In Section 2, the basic real business cycle environment is presented and its long-run properties worked out. The price shocks and the associated cyclical properties of the model are presented in Section 3. Findings for the model version in which there is a trade-off in household production between real money and leisure are described in Section 4. The final section offers some concluding remarks.

2. A Real Model of Aggregate Fluctuations

The model can be thought of as a growth model with technology shocks and includes a time-to-build technology for producing durables. For our purpose, we make these goods consumer durables, although they will play a similar role for some of the model properties as producer durables would have. With our assumptions, leisure choices are intertemporally highly substitutable.

Consider an economy with a large number of households whose utility functions are alike. Each household i wants to maximize

$$E\sum_{t=0}^{\infty}\beta^{t}u(c_{it},d_{it},\ell_{it},\ell_{i,t-1},\ldots),$$

where c_i is consumption, d_i is the stock of durables, the services of which are proportional to the stock, n_i is hours worked, and $0 < \beta < 1$ is a discount factor. The inclusion of past leisure choices in current utility makes intertemporal substitution of leisure an important feature of the model. The idea is that the more one has worked in the (recent) past, the more disutility is derived from working in period t. An interpretation is that a fraction of ones nonmarket time is spent accumulating a form of household capital which yields utility in the future.

The functional form of the current-period utility function is assumed to be

$$u(c_t,d_t,\ell_t,\ell_{t-1},\ldots) = [c_t^{\mu}d_t^{\theta}(\textstyle\sum_{i=0}^{\infty}\alpha_i\ell_{t-i})^{1-\mu-\theta}]^{1-\gamma}/(1-\gamma),$$

where μ, θ, and γ are given nonnegative parameters, with $\mu + \theta < 1$. The α's are assumed to be such that $0 < \alpha_0 \leq 1$, $\alpha_{i+1}/\alpha_i = 1 - \eta$ for $0 < \eta < 1$ and $i = 1, 2, \ldots$, and $\sum_{i=0}^{\infty}\alpha_i = 1$. Thus, α_0 and η determine the values of all α's. The case of $\alpha_0 = 1$ corresponds to a time-separable utility function. Without loss of generality, we assume that the total time allocation available for market and nonmarket activity is one, that is, $\ell_t = 1 - n_t$ in every period. Then

$$\sum_{i=0}^{\infty}\alpha_i\ell_{t-i} = 1 - \alpha_0 n_t - (1-\alpha_0)\eta a_t,$$

where $a_t \equiv \sum_{i=1}^{\infty}(1-\eta)^{i-1}n_{t-i}$, whose law of motion can be written as

$$a_{t+1} = (1-\eta)a_t + n_t.$$

This special case of the CES function with unitary elasticities between the goods was chosen for two reasons. First, within this class, it is consistent with long-run hours worked per person being roughly constant, as in postwar U.S. data, in spite of a large increase in real compensation. Second, evidence of unitary elasticity between consumer durables and nondurables is that the long-run share of nominal expenditures on durables has remained essentially constant in the postwar period in the face of a sizable decline in their price.

The aggregate production function is $Y_t = \sum_i \lambda_{it} n_{it}$, where Y_t is aggregate output and λ_{it} is the productivity of worker i. In equilibrium, the real wage rate w_{it} for person i will be equal to his productivity. The budget constraint is

$$c_{it} + z_{it} + P_{bt} b_{i,t+1} = w_{it} n_{it} + b_{it},$$

where z_{it} is purchases of durables, b_{it} is one-period loans (or debt if negative) in period t, which sum to zero across all households, and P_{bt} is the price of loans, from which we can implicitly define the interest rate r_t by $1/(1+r_t) = P_{bt}$.

Stocks of finished and unfinished consumer durables are governed by the laws of motion

$$d_{i,t+1} = (1-\delta)d_{it} + s_{i1t},$$

$$s_{ij,t+1} = s_{i,j+1,t}, \quad j = 1, \ldots, J - 1,$$

where $0 < \delta < 1$ is the depreciation rate and s_{i1t} is the addition to the stock of durables initiated in period $t - J + 1$. Suppose additions to durables planned in period t do not start producing services until period $t + J$, as expressed by the equations above. The expenditures, however, are distributed with a fraction ϕ_j in the jth stage from the last for all j. Formally, then, total expenditures on durables in period t are

$$z_{it} = \sum_{j=1}^{J} \phi_j s_{ijt}, \quad \text{where} \sum_{j=1}^{J} \phi_j = 1.$$

Suppose now that the individual technology shocks are distributed around economy-wide means, and that people live on "islands" in the sense suggested by Phelps (1970). This setup yields a distribution of equilibrium real wages. The island-specific technology shocks, λ_{it}, are assumed to be distributed around the economy-wide mean, Λ_t, which itself is subject to change over time according to a first-order autoregressive process:

$$\Lambda_t = \rho\Lambda_{t-1} + K + H_t,$$

$$\lambda_{it} = \Lambda_t + \varepsilon_{it}, \quad \forall i.$$

The disturbances are assumed to be independently and normally distributed with means zero and variances σ_H^2 and σ_ε^2.

Laws of motion analogous to those of individual variables can be written down for the aggregate or per capita quantities D_t, Z_t, S_{1t}, ..., S_{Jt}, and A_t. Of course, we have $B_t = 0$ in every period. The distinction between individual and aggregate variables, here represented by lower-case and upper-case letters, respectively, is important when computing the equilibrium of certain types of models. In particular, this is true in models with government policy, in our case monetary policy. The details of how dynamic general equilibrium can be computed in such cases in which it is not the solution of a stand-in planner's problem are given in Kydland (1989).

In what follows, I assume that the structure of the model is such that maximizing behavior leads to linear decision rules. This makes the model computationally feasible. The objective function used for these computations is the utility function after substitution has been made from the nonlinear budget constraint. The economy is approximated by a quadratic around the steady state which is determined analytically. Christiano (1990) and Danthine, Donaldson, and Mehra (1989) find that this approach provides a close approximation to the outcomes of exact nonlinear models in this class. A contributing factor is that the deviations from the long-run path in aggregate data are relatively small.

There is a great deal of a priori knowledge that can be used to place restrictions on parameters, such as capital depreciation rates, capital-output ratios, weights on lags in expenditures on durables, elasticity of long-run labor supply, etc. Such restrictions are easily imposed within this framework and in principle leave no free parameters, although accurate measurements are not necessarily available for all of them at this point.

To obtain the steady state, I first substitute for c_t from the budget constraint into the utility function. Omitting time subscripts for steady states, we have (since b=0 and z=s)

$$c = wn + s,$$

where $w = W$. We also have $s = \delta d$ and $n = \eta a$.

If there is no lag in the production of durables, that is, $J = 1$, the implicit steady-state rental price q of durables in terms of nondurables is $r + \delta$, where r is given by $1/(1+r) = \beta$. If, on the other hand, it takes time to produce durables, then this price becomes

$$q = (r+\delta) \sum_{j=1}^{J} (1+r)^{j-1} \phi_j.$$

To determine relations between the steady-state values of c, d, and n on the one hand and values of the parameters μ and θ on the other, suppose first that the sum of services from nondurables and durables is $c + qd$. Then, from the condition $MU_\ell/MU_c = w$, one obtains

$$(1-\mu-\theta) \sum_{i=0}^{\infty} \beta^i \alpha_i/\ell = (\mu+\theta)w/(c+qd).$$

Using the facts that $\sum_{i=0}^{\infty} \beta^i \alpha_i = (\alpha_0 r+\eta)/(r+\eta) \equiv \sigma$ and $n = 1 - \ell$, this condition can be rewritten as

$$\mu + \theta = \frac{\sigma(c+qd)}{\sigma(c+qd) + (1-n)w}.$$

The values of μ and θ now follow from the condition

$$\frac{\mu}{\theta} = \frac{c}{qd}.$$

The model is calibrated as follows. The discount factor β is chosen such that $(1-\beta)/\beta = r = 0.01$, corresponding to a four percent annual real interest rate. The depreciation rate of durables is 0.05, while that of household capital, η, is set equal to 0.10. Furthermore, we set $\alpha_0 = 0.50$. The last two values are consistent with those estimated by Hotz, Kydland, and Sedlacek (1988) using annual panel data. For comparison, in some experiments α_0 is set equal to one. The value of γ is two, which means a little more curveture than that corresponding to logarithmic utility.

The share of time allocation, net of sleeping time and personal care, allocated to market activity is set equal to 0.3. The share of output going to investment in durables is 0.3, corresponding roughly to the fraction spent on producer and consumer durables in the U.S. economy. From these values, it follows that $\mu = 0.20$ and $\theta = 0.10$. Average Λ is chosen so that steady-state output is always one. The time to build durables, J, is assumed to equal three, and the values of ϕ_1, ϕ_2, and ϕ_3 are therefore one-third.

When values have been assigned to the parameters and the corresponding steady state determined, the quadratic approximation around the steady state can be made. The resulting structure fits into the general framework outlined in Kydland (1989), and the dynamic competitive equilibrium can be determined as described there. This equilibrium is in the form of a set of stochastic difference equations, on the basis of which the covariance structure of the model economy can be computed.

The elements described in this section are the basis for the models used in Sections 3 and 4. I first turn to the model with imperfect information about aggregate and individual real wages due to aggregate price shocks.

3. The Island Economy With Aggregate Price Shocks

Suppose that productivity is affected by shocks that are distributed around economy-wide means as described in the preceding section, thus yielding a distribution of real wages. I now extend the model to allow for correlated price shocks. Each individual observes only his own nominal wage rate (or the wage rate on his "island") before making the decision on how much to work in period t. From the observed nominal wage rate, say $\hat{w}_{it}$, and knowledge of relative variances of the shocks, he makes inference about his own real wage rate, w_{it}, and also about the economy-wide real wage, W_t.

To be specific, assume that

$$\hat{w}_{it} = w_{it} + \pi_t,$$

where π_t can be thought of as an aggregate price shock. Since the worker prefers to supply more labor when his real wage is high relative to what he can expect in the future, an indication of which is the economy-wide real wage rate, he tries to infer the values of w_{it} and W_t from the observation of $\hat{w}_{it}$. In this setup, if the worker sees a change in $\hat{w}_{it}$, he does not know how much is due to a monetary shock, π_t, to economy-wide productivity, H_t, or to a change in the difference between his own and the average productivity, ε_{it}. His knowledge, however, of the relative variances of the three shocks helps him form conditional expectations. Having decided how many hours to work, he later learns what his actual real income turned out to be in that period. If it is higher, say, than anticipated, he will probably allocate a larger proportion of his income to durables, yielding services in future periods, and to lending (or reduced borrowing) than he otherwise would have. The implicit assumption is that temporary changes are sufficiently short-lived that people would not consider moving to a different island, but that consumption goods can be traded across islands.

To summarize so far, we have

$$W_t = \rho W_{t-1} + K + H_t \equiv W_t^e + H_t,$$

$$w_{it} = W_t + \varepsilon_{it},$$

$$\hat{w}_{it} = w_{it} + \pi_t,$$

where the random variables H_t, ε_{it}, and π_t are independently and normally distributed with means zero and variances σ_H^2, σ_ε^2, and σ_π^2. The notation W_t^e stands for the expected value of W_t, conditionally on observations with index less than t. The shock π_t is the same for each individual.

With these assumptions, we have the following conditional expectations (see Graybill 1961, p. 63)

$$E(W_t|\hat{w}_{it}) = (1-\psi_1)W_t^e + \psi_1\hat{w}_{it},$$

where $\psi_1 = \sigma_H^2/(\sigma_H^2+\sigma_\varepsilon^2+\sigma_\pi^2)$, and

$$E(w_t|\hat{w}_{it}) = (1-\psi_2)W_t^e + \psi_2\hat{w}_{it},$$

where $\psi_2 = (\sigma_H^2+\sigma_\varepsilon^2)/(\sigma_H^2+\sigma_\varepsilon^2+\sigma_\pi^2)$.

The major purpose of this exercise is to determine the extent to which price surprises, through this information structure, affect the behavior of the economy. Since the individual cannot distinguish between monetary innovations, π_t, and innovations to productivity at the time when he makes a decision on hours worked, n_t, the effects of both will be identical in the period in which they take place. Subsequent to period t, however, productivity shocks will have persistent effects, while the effects of the price shocks die off quickly.

Consider the case of persistent aggregate productivity shocks as characterized by a value of the autocorrelation parameter ρ of 0.95. There is considerable evidence that productivity shocks are indeed rather long-lived. For the standard case in Table 2, the standard deviations of all three shocks are 0.6 percent. For the aggregate shock, this is about four-fifths of the standard deviation of technology shocks estimated by Prescott (1986) based on U.S. quarterly data since 1954.

In principle, it should be possible to calibrate the relative variance of the sector-specific shocks using productivity data across sectors. For the present purpose, I experiment with some alternatives that will give a feel for the model properties depending on the importance of the island structure and/or the price shocks. This exercise may provide an indication of the payoff to gathering information about these relative variances.

The figures in Table 2 are obtained by drawing 20 independent samples of 138-quarter length. For each sample, the cyclical components are calculated using the same method as for the U.S. data in Table 1. For each statistic, I report the average and the standard deviation of the 20 samples. These are estimates of the means and standard deviations for the sampling distributions of the statistics for the model economy and can be compared with the statistics for the U.S. economy in Table 1.

We see that the average standard deviation for output is 1.81 percent, while that of hours worked is 1.23 percent. A substantial part of that variability is accounted for by the intertemporally nonseparable utility function. For the time-separable case ($\alpha_0=1$), the corresponding figures are 1.17 and 0.49 percent.

To see the extent to which the variability of the price shocks contributes to real variability, consider a series of experiments such as that in Table 2, except that σ_π is changed in steps of 0.1, holding σ_H and σ_ε fixed. The outcome is displayed as the curves labelled I in Figure 4. The percentage standard deviation of cyclical output, σ_y, is largest when there are no price shocks, although there is a slight increase in hours variability up until $\sigma_\pi = 0.4$. This finding is contrary to the standard view that nominal shocks increase output variability.[1] The intuitive reason is that, while a price shock has some effect on real variables, an increase in the variance of price shocks also reduces the magnitude of the response to each technological innovation. While this change may appear stabilizing, it is not without cost since resources are to some extent misallocated as a result.

For small values of the standard deviation of the aggregate technology shock, σ_H, still holding σ_ε fixed, the relation between σ_y and σ_π is indeed hump-shaped, although it is perhaps surprising how soon the top occurs. The case of $\sigma_H = 0.1$ is displayed in Figure 4 with the curves labelled II.

Of separate interest is the role of the "island" or sector shocks. In Figure 5, the variability of the aggregate technology shock and the nominal shock are held fixed ($\sigma_H=\sigma_\pi=0.6$), but σ_ε is varied in intervals of 0.2.

Throughout these experiments, the period length was assumed to be one quarter, which is therefore also how long the sector shocks last. Increasing the period length to half a year or a full year of course changes the numbers, but the qualitative comparisons remain unaffected.

The conclusion of this section is that, in this economy, an increase in the variance of aggregate price shocks increases the variability of output only if the variance of the aggregate technology shock is low and the price-shock variance is not already too high. Too high in this context means about as high as or higher than the variance of the sector-specific technology shocks.

4. Money as a Medium of Exchange

A great deal of recent research on monetary theory has been concerned with money as a store of value. The natural abstraction for that analysis is the overlapping-generations model. Although this work has provided some very interesting insights, it is debatable whether this money-holding motive plays much of a role for quarterly, or even yearly, fluctuations. Instead, I concentrate here on the role of money in facilitating transactions. One approach that has been used is the cash-in-advance model which goes so far as to make an equal amount of money a prerequisite for a given amount of purchases.[2] While this is a useful abstraction for many purposes, it seems like an unnecessarily severe constraint when there is also a time-allocation decision as in the model. It also has proved difficult to get much velocity movement in such models. Instead, I introduce a trade-off between real money and leisure. The idea is that holding more money saves trips to the bank, shopping time, and so on.[3]

In this section, I abstract from the island setup, that is, I let σ_ε equal zero. I assume also that the aggregate technology shock is known before making decisions in every period.

The government has outstanding a nominal stock of money, m_t, when period t begins.[4] The price of money relative to the price of consumption goods is p_t. The budget constraint for the typical individual is

$$c_t + z_t + p_t m_{t+1} = w_t n_t + p_t m_t + p_t v_t,$$

where v_t is a nominal lump-sum transfer from the government. The quantity of leisure saved increases as a function of real money holdings, $p_t m_t$, but at a decreasing rate.[5] I approximate this relation by an exponential function in the relevant range. Net leisure in period t then can be written as $1 - n_t + \omega_0(p_t m_t)^{\omega_1}$, where $\omega_0 > 0$ and $0 < \omega_1 < 1$.

The same method as before is used to determine the steady state and then to approximate around it, and I shall not go through it in detail. A first-order condition with respect to the money stock m (or its change) gives us another equation so that we can solve for pm in terms of the given parameters. If money supply is governed by a stationary rule, this ties down the steady-state price level p.

This model is capable of generating different comovements of prices and output depending on the source of the shock. If it is technological, then employment (or output) and the aggregate price level (the inverse of p_t) are negatively correlated. The initial response to a positive innovation of this type is for the production of both durables and nondurables to rise, with a relatively much greater increase for durables.

A question of some interest is what magnitudes of price changes are possible with no fluctuation in the money stock. The values assumed for ω_0 and ω_1 are 0.12 and 0.50, respectively. These magnitudes can probably best be understood by a marginal evaluation at the steady-state real money stock, pm. If steady-state hours of work are 40 per week, say, and if the real money stock is increased by one percent relative to its steady state, then the resulting saving in leisure is less than one minute.

The cyclical statistics from the model are presented in Table 3. The statistics for the real variables are close to those for the case of the model in the preceding section in which both sector and price shocks have zero variance. The correlation coefficient of the price level (conventionally measured) with GNP is -0.89 and its cyclical standard deviation 0.74. It is interesting to note that, without the lag in the production of durables, the price fluctuation is somewhat smaller.

Using a time-separable utility function in leisure, the output variation is reduced from 1.62 to 1.16 percent, hours variation from 0.94 to 0.43 percent, and price level variation to 0.67 percent. In other words, output and hours variation are substantially reduced with very little reduction in price variability. This finding with regard to the price level makes intuitive sense. In the nonseparable case, the immediate effect on current marginal utility of, say, working one hour more is smaller. Instead, future utility is also adversely affected in a direct way by such an increase in current hours of work. Therefore, the increase in current demand for money for leisure-saving purposes is relatively smaller.

Velocity in the model moves procyclically with a standard deviation of just over one. With the constant money stock (abstracting from growth), the price fluctuation that results from this model is surely smaller than what we observe. Still, the constant-money-stock benchmark (interpreted as constant growth rate) is capable of producing at least one-half of the price variability observed in the U.S. Some fluctuation in the money stock would increase the price fluctuation. The correlations with real GNP are not inconsistent with the data, especially after adding some monetary shocks in the form of uncorrelated changes over time in the nominal money stock. For example, if the standard deviation of changes in the money stock is 0.5 percent, then the standard deviation of the price level increases to 1.06 percent, that of velocity to 1.23 percent, and the contemporaneous correlation coefficient between the conventional price level and output becomes -0.58. While these preliminary findings are quantitatively believable, a more careful calibration of the model is clearly needed. Our results seem sufficiently encouraging to make such an effort worthwhile.

5. Discussion

The goal of this paper was to assess the quantitative importance of money in a real business cycle model. The exercise was carried out in two steps. The first introduced price shocks in a version which featured temporary sector-specific technology shocks as well as persistent economy-wide shocks. The "island" shocks added some variability, but the extent of variability of the price shocks made surprisingly little difference beyond that.

In the second step, issues of imperfect information about wage rates were ignored. Instead, the focus was on the variability of nominal variables and their comovements with real GNP. With a trade-off in the household between leisure and real money, various possibilities exist for the interaction of real and nominal variables, in particular depending on what gives rise to hours fluctuation. The benchmark of no variability in the money stock can account for at least half of the price variation observed in the U.S. economy since the Korean War. Adding some monetary shocks could conceivably account for most of the price variation while still being consistent with the observed procyclical velocity and countercyclical price level.

The approach of introducing separately the two monetary mechanisms was intended to isolate their implications. In reality, what could be going on is that features such as those described in the second step give rise to countercyclical price-level fluctuations that are well understood by agents when making their decisions. In addition, then, there are stochastic price surprises with their particular real effects and which need not be strong enough to prevent prices from moving countercyclically. It is interesting to note, however, that neither one of these mechanisms gives rise to any output or hours variability to speak of. With aggregate technology shocks of reasonable magnitude, I find that, for this model environment, larger price-surprise variability lowers the variability of output.

In addition to the leisure-saving motive at the household level, one could also introduce a trade-off between real money and labor in producing output in the firm. Then one could also use information about quantity of money held by households versus firms as well as other information of relevance for determining values of the parameters related to liquidity services. An empirical measure of liquidity would be needed for the purpose of checking the model's consistency with observations. Such a measure could be constructed along the lines of for example Barnett, Offenbacher, and Spindt (1984). The rental prices of various financial assets could be used to determine measures of their liquidity services to be added up.

One particularly striking empirical puzzle is the high volatility of the rental price of liquidity as highlighted by Lucas (1988). The type of model discussed above could potentially be used to shed some light on that issue and perhaps remove some of the puzzle. The procyclical wage predicted by the theory as well as the propagation mechanisms for the shocks can yield patterns of money-demand behavior which are not captured very well by standard demand-for-money relations. On the other hand, in most periods, short-run nominal interest-rate movements are probably dominated by inflation expectations. I have not yet studied the important case of systematically variable money growth. I have also abstracted from the consumption-smoothing motive for holding cash in heterogeneous-agent environments, which has been studied by Imrohoroglu (1989), Diaz-Gimenez and Prescott (1989), and Kehoe, Levine and Woodford (1989).

This paper is concerned with short-run monetary changes and their effects. Finding real effects of any magnitude proved to be challenging. This does not rule out that longer-run monetary changes resulting in changes in inflation could have real effects. For example, higher inflation under a nonindexed tax system may result in an increase in the tax burden on physical and human capital if no offsetting changes are made in the tax structure. This effect may have been a contributing factor to the slower growth experienced in the 70s.

Footnotes

*An earlier version of this paper appeared as Hoover Institution Working Paper No. 83-10. Previous drafts included a section describing a direct method for computing dynamic aggregate equilibrium in models of the type considered in this paper in which solving a stand-in planner's problem is inappropriate. That section has since been published in Kydland (1989).

[1] A fairly recent account of that view is in Kormendi and Meguire (1984).

[2] See Clower (1976) and more recent analyses by Lucas (1980), Svensson (1985), Lucas and Stokey (1987), and others. Both Greenwood and Huffman (1987) and Cooley and Hansen (1989) use cash-in-advance models to address cyclical issues, and, in the latter case, to assess the welfare implications of inflation.

[3] This view is implicit in, for example, Brunner and Meltzer (1971). An alternative model is simply to let money balances be an argument of the utility function. As McCallum (1983) points out, such a utility function can be regarded as the indirect function obtained after substituting for the transactions technology. My view is that being explicit about the household transactions technology gives one a better chance of obtaining the measurements needed to calibrate the model.

[4] The distinction between inside and outside money is abstracted from here. King and Plosser (1984) discuss the qualitative properties of a real business cycle model with a financial sector producing transactions services. The figures in Table 1

support their view that making the distinction between inside and outside money is important for understanding the role of money, broadly defined. For example, the table suggests that, while cyclical M1 moves without any clear lead-lag pattern relative to GNP, monetary base has a tendency to lag and M2 to lead GNP.

[5] One could also let the trade-off be a function of expenditures. Since hours and consumption have a fairly high correlation, that modification would increase somewhat the amplitude of the price level. Thus, abstracting from it gives a conservative estimate of how much of the volatility of the price level and the velocity is accounted for. Finally, one could let transactions require the use of physical resources, rather than time, as is done in Sims (1989). While that is not unreasonable, the view here is that time is the main resource expended in the act of carrying out the transactions involved in this environment.

Figure 1

U.S. Real GNP with Trend (log scale)

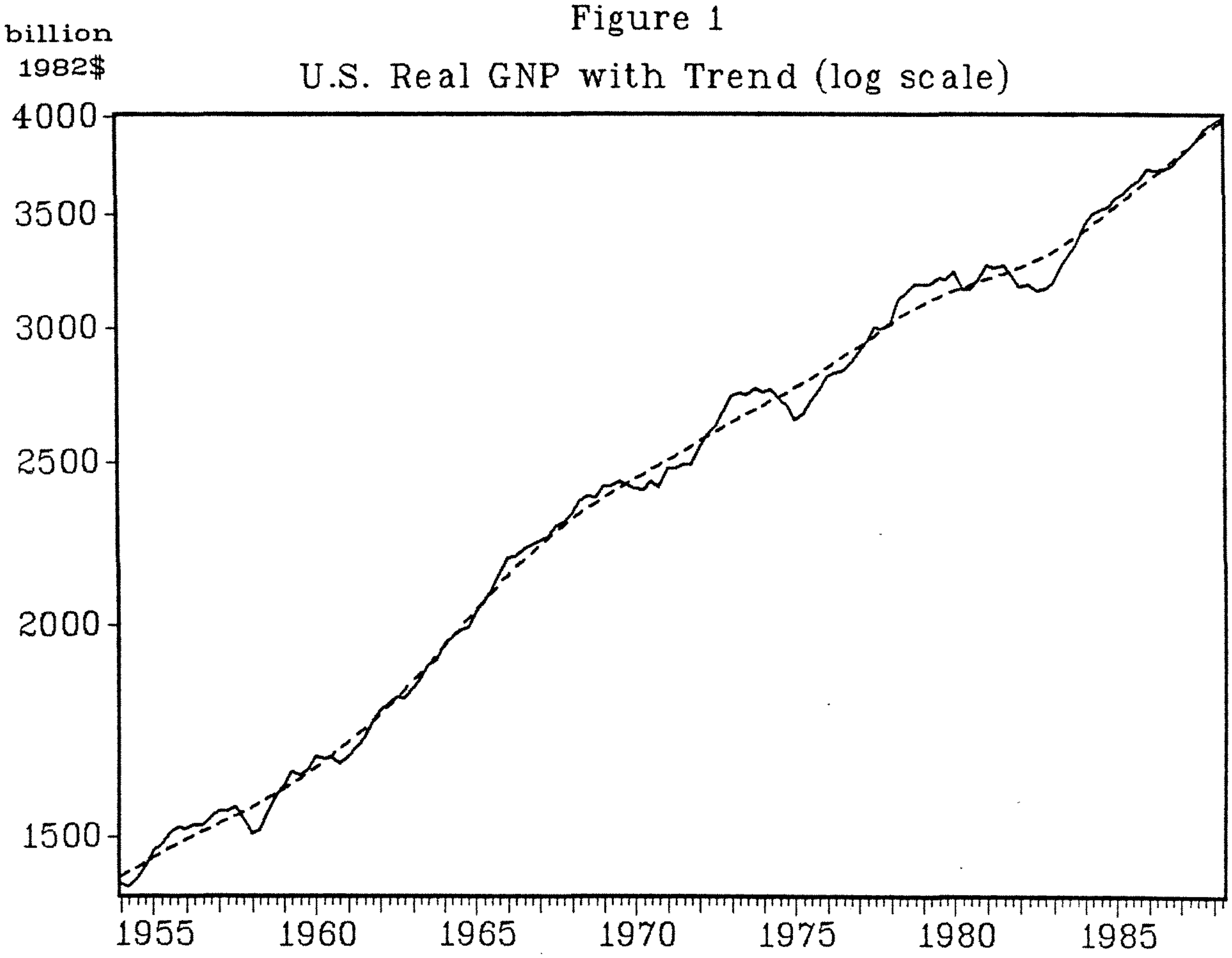


Figure 2

Cyclical Real GNP vs. Nominal M1

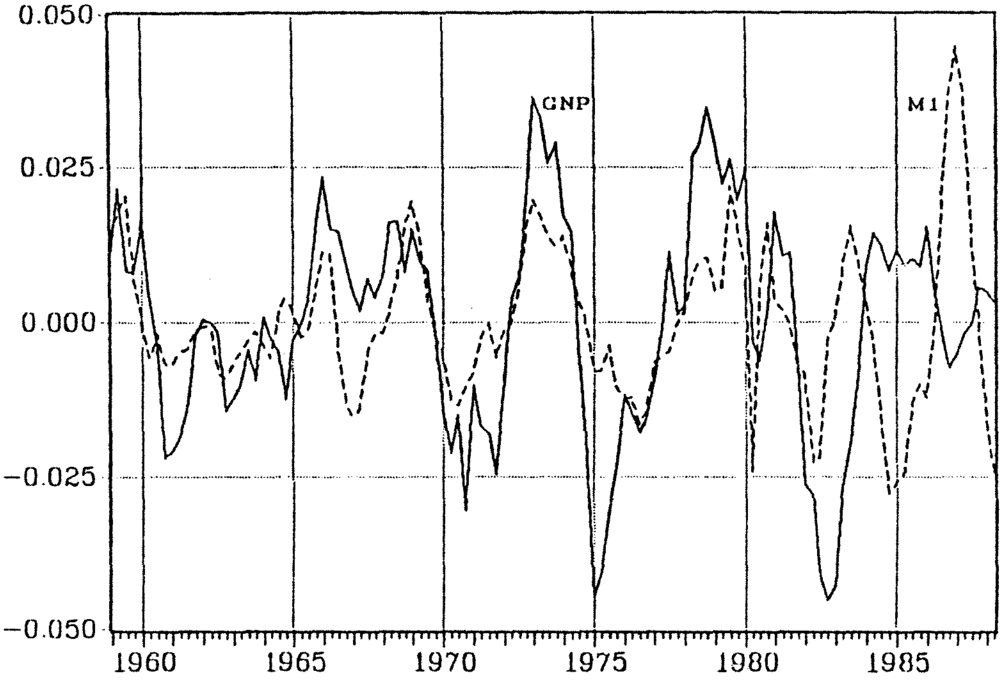


Figure 3

Cyclical Real GNP vs. CPI

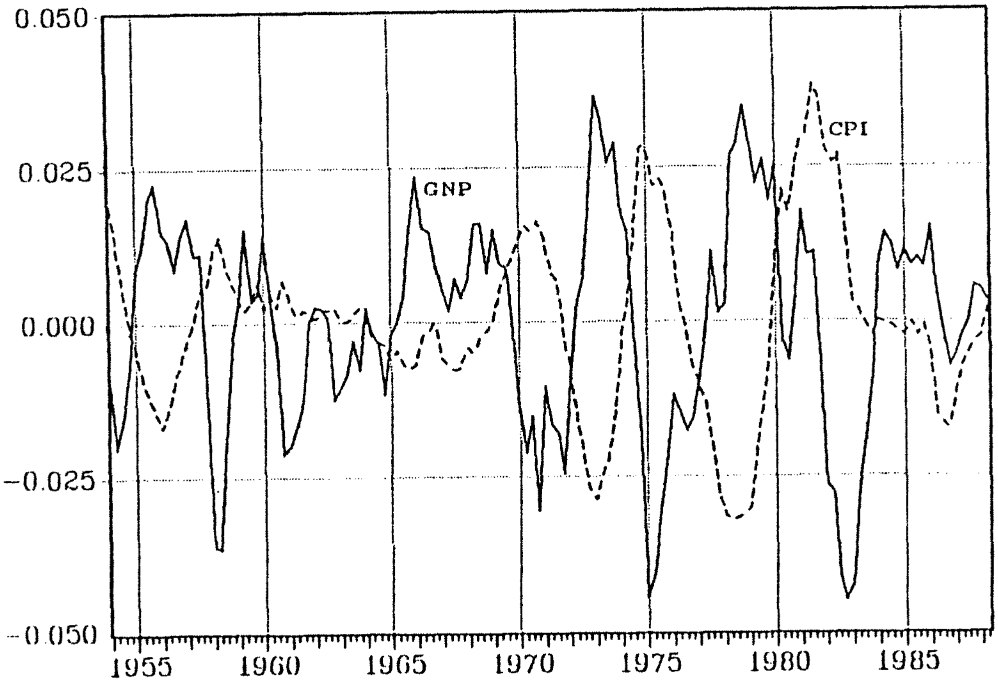
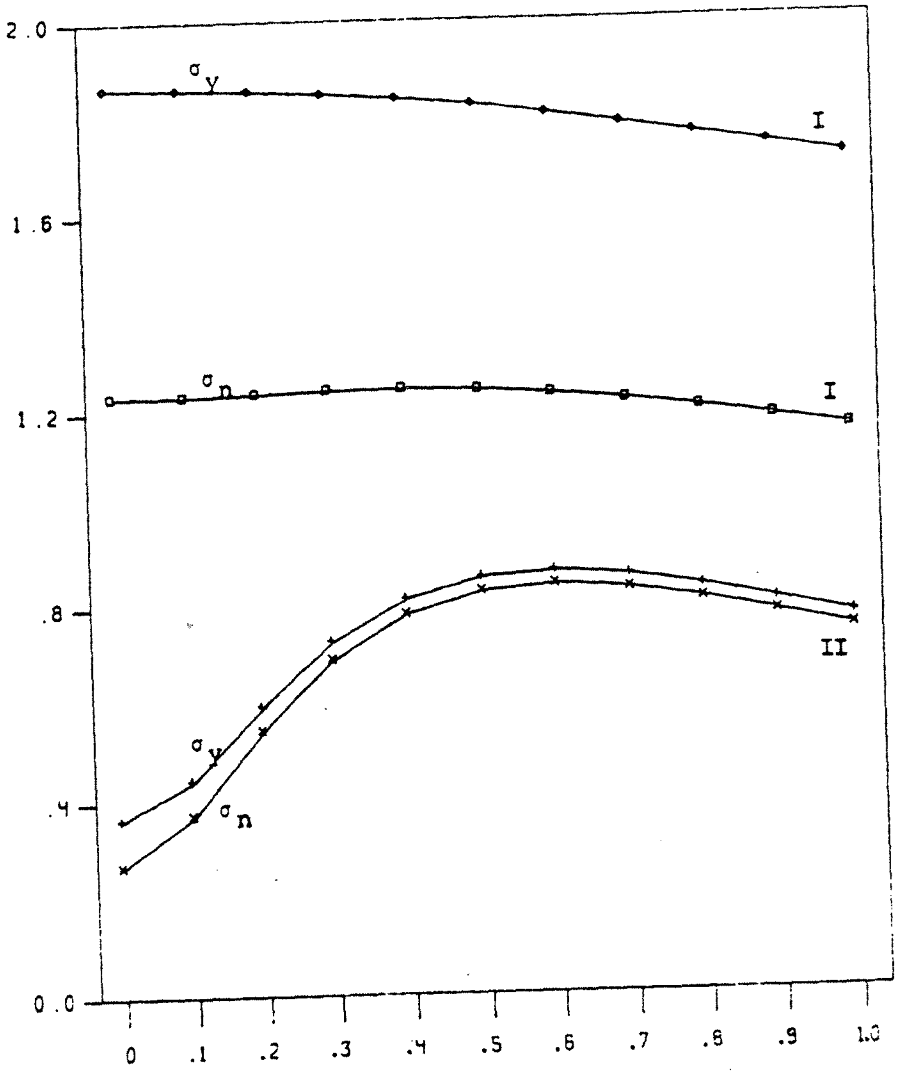


FIGURE 4

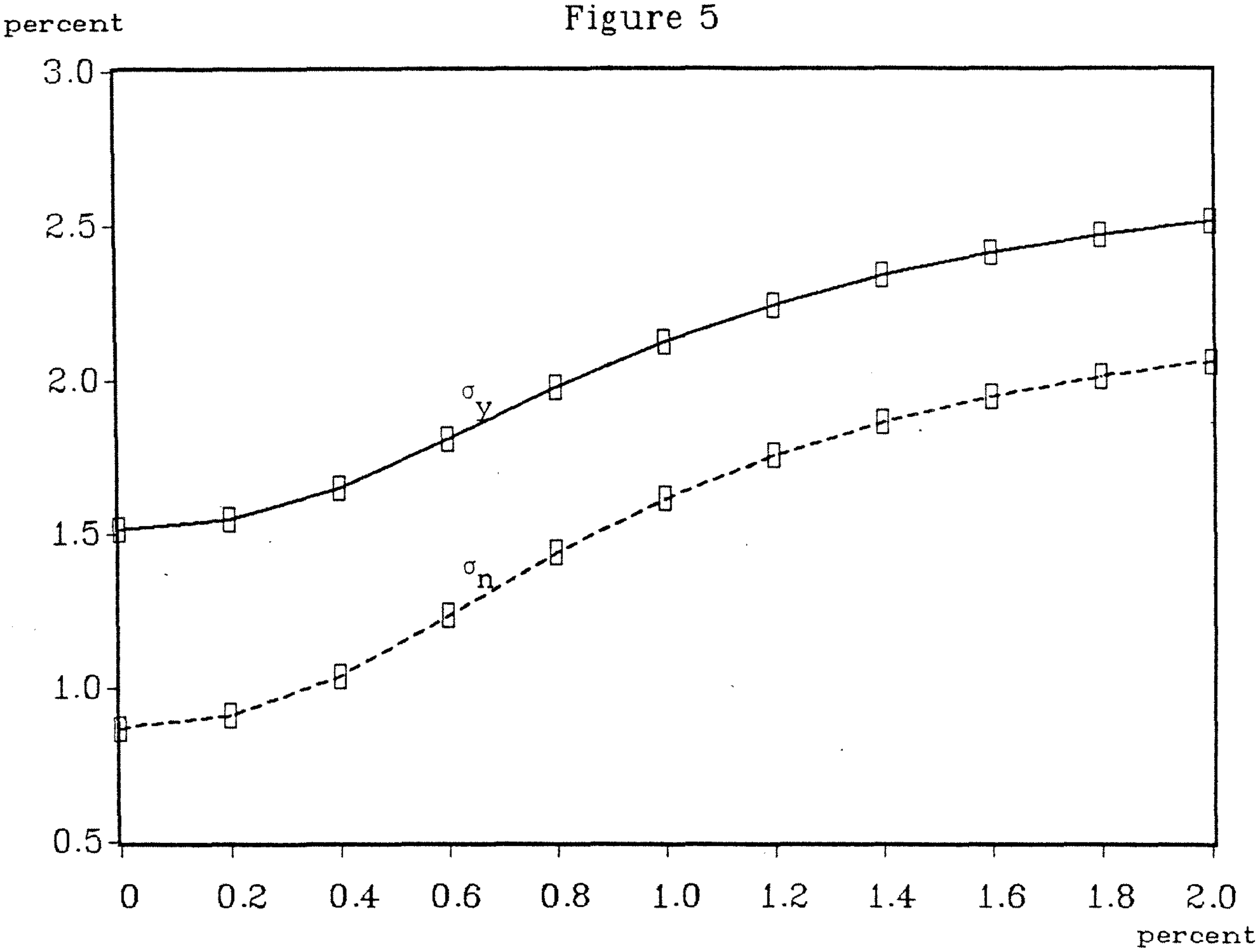


Relation between output and hours variability and price-surprise variability, holding standard deviation of island productivity shocks constant (0.6 percent).

I: 0.6 percent standard deviation of aggregate productivity shock.

II: 0.1 percent standard deviation of aggregate productivity shock.

Figure 5



Relations between output and hours variability and island-productivity variability, holding standard deviations of aggregate productivity and of price surprises constant (both equal 0.6 percent).

Table 1

Cyclical behavior of the U.S. economy:
Deviations from trend of key variables, 1954:1-1988:2[a]

		Cross-correlation of output with										
Variables x	Std. dev.	x(t-5)	x(t-4)	x(t-3)	x(t-2)	x(t-1)	x(t)	x(t+1)	x(t+2)	x(t+3)	x(t+4)	x(t+5)
Output Components												
Gross National Product	1.74%	-0.03	0.15	0.38	0.63	0.85	1.00	0.85	0.63	0.38	0.15	-0.03
Consumption Expenditures												
Services & Nondurable Goods	0.86	0.20	0.38	0.53	0.67	0.76	0.76	0.63	0.47	0.28	0.07	-0.10
Durable Goods	5.08	0.25	0.38	0.50	0.65	0.74	0.77	0.60	0.37	0.10	-0.14	-0.32
Fixed Investment Expenditures	5.51	0.09	0.26	0.44	0.65	0.83	0.90	0.81	0.60	0.35	0.08	-0.14
Labor Input												
Hours (Household Survey)	1.50	-0.11	0.05	0.23	0.44	0.68	0.86	0.86	0.75	0.60	0.38	0.18
Hours (Establishment Survey)	1.69	-0.23	-0.07	0.14	0.39	0.67	0.88	0.92	0.81	0.64	0.42	0.21
Prices												
GNP Deflator	0.89	-0.51	-0.62	-0.69	-0.70	-0.65	-0.56	-0.44	-0.32	-0.18	-0.05	0.08
CPI	1.43	-0.52	-0.64	-0.72	-0.73	-0.69	-0.58	-0.43	-0.25	-0.06	0.14	0.30
Monetary Aggregates[b]												
Monetary Base	0.76	-0.12	0.02	0.15	0.26	0.37	0.44	0.44	0.42	0.38	0.34	0.32
M1	1.26	-0.04	0.10	0.23	0.36	0.40	0.37	0.27	0.20	0.14	0.12	0.11
M2	1.51	0.48	0.60	0.67	0.68	0.61	0.46	0.25	0.05	-0.15	-0.33	-0.46
Velocity[b]												
M1	1.60	-0.25	-0.19	-0.10	0.04	0.22	0.44	0.43	0.36	0.25	0.12	-0.01

[a] Data Source: Citibase

[b] For the period 1959:1-1988:2

Table 2

Cyclical behavior of economy with price shocks[a]

Variables x	Std. dev.	Cross-correlation of output with x(t-5)	x(t-4)	x(t-3)	x(t-2)	x(t-1)	x(t)	x(t+1)	x(t+2)	x(t+3)	x(t+4)	x(t+5)
Output	1.81	-0.11	-0.04	-0.01	0.27	0.49	1.00	0.49	0.27	-0.01	-0.04	-0.11
	(0.17)	(0.09)	(0.07)	(0.08)	(0.09)	(0.08)	(0.00)	(0.08)	(0.09)	(0.08)	(0.07)	(0.09)
Nondurable Consumption	0.69	-0.21	-0.14	-0.12	0.20	0.46	0.93	0.57	0.40	0.24	0.10	0.02
	(0.08)	(0.08)	(0.06)	(0.08)	(0.08)	(0.06)	(0.01)	(0.08)	(0.09)	(0.09)	(0.09)	(0.10)
Durables Expenditures	4.56	-0.08	-0.01	0.03	0.29	0.48	0.99	0.44	0.22	-0.10	-0.09	-0.16
	(0.40)	(0.09)	(0.07)	(0.09)	(0.09)	(0.09)	(0.002)	(0.08)	(0.08)	(0.08)	(0.06)	(0.08)
Hours	1.23	-0.04	0.02	0.03	0.28	0.42	0.95	0.34	0.14	-0.17	-0.13	-0.18
	(0.09)	(0.10)	(0.07)	(0.09)	(0.09)	(0.10)	(0.01)	(0.09)	(0.08)	(0.07)	(0.05)	(0.08)

[a] These are the means of 20 simulations, each of which was 138 periods long. The numbers in parentheses are standard deviations.

Table 3

Cyclical behavior of economy with money-leisure trade-off[a]

		Cross-correlation of output with										
Variables x	Std. dev.	x(t-5)	x(t-4)	x(t-3)	x(t-2)	x(t-1)	x(t)	x(t+1)	x(t+2)	x(t+3)	x(t+4)	x(t+5)
Output	1.62	-0.15	-0.06	0.06	0.35	0.66	1.00	0.66	0.35	0.06	-0.06	-0.15
	(0.18)	(0.08)	(0.07)	(0.08)	(0.07)	(0.05)	(0.00)	(0.05)	(0.07)	(0.08)	(0.07)	(0.08)
Nondurable Consumption	0.66	-0.25	-0.17	-0.08	0.25	0.58	0.95	0.69	0.47	0.28	0.13	0.02
	(0.08)	(0.08)	(0.06)	(0.07)	(0.06)	(0.04)	(0.01)	(0.06)	(0.08)	(0.09)	(0.09)	(0.09)
Durables Expenditures	3.97	-0.11	-0.01	0.11	0.38	0.67	0.99	0.63	0.29	-0.03	-0.13	-0.21
	(0.43)	(0.08)	(0.07)	(0.08)	(0.08)	(0.05)	(0.001)	(0.05)	(0.07)	(0.07)	(0.06)	(0.08)
Hours	0.94	-0.07	0.03	0.15	0.39	0.66	0.97	0.59	0.24	-0.12	-0.20	-0.27
	(0.10)	(0.08)	(0.08)	(0.08)	(0.08)	(0.05)	(0.005)	(0.04)	(0.06)	(0.07)	(0.06)	(0.07)
Price Level	0.74	0.29	0.22	0.13	-0.20	-0.54	-0.89	-0.67	-0.49	-0.37	-0.20	-0.09
	(0.09)	(0.07)	(0.06)	(0.07)	(0.06)	(0.04)	(0.01)	(0.06)	(0.08)	(0.08)	(0.09)	(0.10)
Velocity	1.02	-0.03	0.06	0.19	0.41	0.66	0.95	0.57	0.20	-0.17	-0.24	-0.30
	(0.11)	(0.09)	(0.08)	(0.08)	(0.08)	(0.05)	(0.01)	(0.04)	(0.06)	(0.06)	(0.05)	(0.07)

[a] These are the means of 20 simulations, each of which was 138 periods long. The numbers in parentheses are standard deviations.

References

Barro, Robert J. 1976. Rational expectations an the role of money. Journal of Monetary Economics 2, 1-32.

Barnett, William A.; Offenbacher, Edward K.; and Spindt, Paul A. 1984. The new Divisia monetary aggregates. Journal of Political Economy 92, 1049-1085.

Brunner, Karl, and Meltzer, Allan H. 1971. The uses of money: Money in a theory of an exchange economy. American Economic Review 61, 784-805.

Christiano, Lawrence J. 1990. Linear quadratic approximation and value function iteration: A comparison. Forthcoming in Journal of Business and Economic Statistics 8.

Clower, Robert W. 1976. A reconsideration of the microfoundation of monetary theory. Western Economic Journal 6, 1-8.

Cooley, Thomas F., and Hansen, Gary D. 1989. The inflation tax in a real business cycle model. American Economic Review 79, 733-748.

Danthine, Jean-Pierre; Donaldson, John B.; and Mehra, Rajnish. 1989. On some computational aspects of real business cycle theory. Journal of Economic Dynamics and Control.

Diaz-Gimenez, Javier, and Prescott, Edward C. 1989. Asset returns in computable general equilibrium heterogeneous agent economies. Federal Reserve Bank of Minneapolis Working Paper.

Graybill, Franklin A. 1961. An Introduction to Linear Statistical Models vol. I. New York: McGraw-Hill.

Greenwood, Jeremy, and Huffman, Gregory W. 1987. A dynamic equilibrium model of inflation and unemployment. Journal of Monetary Economics 19, 203-228.

Hodrick, Robert J., and Prescott, Edward C. 1980. Post-war U.S. business cycles: An empirical investigation. Carnegie-Mellon University Working Paper.

Hotz, V. Joseph; Kydland, Finn E.; and Sedlacek, Guilherme L. 1988. Intertemporal preferences and labor supply. Econometrica 56, 335-360.

Imrohoroglu, Ayse. 1989. The welfare cost of inflation under imperfect insurance. University of Southern California Working Paper.

Kehoe, Timothy J.; Levine, David K.; and Woodford, Michael. 1989. The optimum quantity of money revisited. Federal Reserve Bank of Minneapolis Working Paper No. 404.

King, Robert G., and Plosser, Charles I. 1984. Money, credit, and prices in a real business cycle. American Economic Review 74, 363-380.

Kormendi, Roger C., and Meguire, Philip G. 1984. Cross-regime evidence of macroeconomic rationality. Journal of Political Economy 92, 875-908.

Kydland, Finn E. 1989. Monetary policy in models with capital. In Dynamic Policy Games in Economies, eds. F. van der Ploeg and A. J. de Zeeuw. Amsterdam: North-Holland.

Kydland, Finn E., and Prescott, Edward C. 1980. A competitive theory of fluctuations and the feasibility and desirability of stabilization policy. In Rational Expectations and Economic Policy, ed. S. Fischer. Chicago: NBER and University of Chicago Press.

Kydland, Finn E., and Prescott, Edward C. 1982. Time to build and aggregate fluctuations. Econometrica 50, 1345-1370.

Long, John B., Jr., and Plosser, Charles I. 1983. Real business cycles. Journal of Political Economy 91, 39-69.

Lucas, Robert E., Jr. 1972. Expectations and the neutrality of money. Journal of Economic Theory 4, 103-124.

Lucas, Robert E., Jr. 1975. An equilibrium model of the business cycle. Journal of Political Economy 83, 1113-1144.

Lucas, Robert E., Jr. 1980. Equilibrium in a pure currency economy. In Models of Monetary Economics, eds. J. H. Kareken and N. Wallace. Federal Reserve Bank of Minneapolis.

Lucas, Robert E., Jr. 1988. Money demand in the United States: A quantitative review. Carnegie-Rochester Conference Series on Public Policy. New York: North Holland.

Lucas, Robert E., Jr. and Stokey, Nancy L. 1987. Money and interest in a cash-in-advance economy. Econometrica 55, 491-514.

McCallum, Bennett T. 1983. The role of overlapping-generations models in monetary economics. Carnegie-Rochester Conference Series on Public Policy. New York: North Holland.

Phelps, Edmund S. 1970. Introduction: The new microeconomics in employment and inflation theory. In E. S. Phelps et al., Microeconomic Foundations of Employment and Inflation Theory. New York: Norton.

Prescott, Edward C. 1986. Theory ahead of business cycle measurement. Carnegie-Rochester Conference Series on Public Policy. New York: North Holland.

Sims, Christopher A. 1989. Models and their uses. Discussion Paper 11, Institute for Empirical Macroeconomics, Minneapolis.

Svensson, Lars E. O. 1985. Money and asset prices in a cash-in-advance economy. Journal of Political Economy 93, 919-944.