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THE ROLE OF MONEY IN A BUSINESS CYCLE MODEL

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ABSTRACT

Two mechanisms are considered through which money plays a role in a real business cycle model. One is in the form of aggregate price surprises. 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 in the household between real money and leisure. This mechanism is associated with considerable price fluctuation even when the nominal money stock does not vary. As is the case for the U.S. economy over the postwar period, the price level is then countercyclical. With neither mechanism do nominal shocks account for more than a small amount of variability in real output and in hours worked. Indeed, a finding is that output variability very well may be lower the larger is the variance of price surprises.

A 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 been published in Kydland (1989).

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1. *Introduction*

Prior to the 1980s, many business cycle theorists, influenced by the Friedman and Schwartz (1963) monetary history, which documented an association between aggregate economic activity and the money stock, focused on monetary disturbances as a prime candidate for the basic impulse generating business cycles. While such shocks easily can be transmitted to real aggregates if prices are "sticky" (see overview in McCallum 1989), the 1970's saw a flurry of research activity directed towards finding a role for money when prices clear markets at all times. A key to this work was the question of whether a sufficiently potent propagation mechanism (in the language of Frisch 1933) could be found to generate cycles of the length and magnitude that we observe. A prominent example of such a theory is in Lucas (1972). Moreover, Barro (1977) found some empirical support for this theory. The idea was that individuals and firms make decisions on the basis of preliminary price information, and that the indicators of the relative prices used in decisions are contaminated by unpredictable central-bank behavior. At a more casual level, this view was consistent with the perception of a procyclical aggregate price level.

Ultimately, of course, one is interested in not just the *theoretical* possibility of a particular source of fluctuations, but also its *quantitative* importance. The aim of this paper is to take a step in that direction. Thus, it complements similar investigations of the quantitative role of technology shocks for the business cycle (e.g., Hansen 1985, Kydland and Prescott 1982). The models used to address that question build upon neoclassical growth theory and impose the quantitative growth facts. Estimates of the role of technology shocks have been found to depend on the ability and willingness of households and firms to substitute intertemporally. Such factors surely are important for the quantitative role of monetary shocks as well. Combining monetary features with an explicit specification of preferences (or home production) and technology, many of whose parameter values can be measured or inferred quite easily, offers the potential for obtaining an 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 enabling one to consider fluctuations of nominal variables, such as the money stock, velocity, and the price level, and their comovements with real aggregates over the business cycle. A model feature considered in this paper is a trade-off between a household's quantity of real money and leisure (saving trips to the bank, shopping time, etc.). This trade-off is of particular interest in this model environment in view of the importance of the labor input for business-cycle theory. It is the focus of the latter part of the paper.

In Table 1, some descriptive statistics for the postwar U.S. economy are presented. The logarithm of each time series is decomposed into a trend and a cyclical component using the method described in Hodrick and Prescott (1980). Figure 1 displays 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 along with nominal M1 in Figure 2 and with the CPI in Figure 3. All monetary aggregates are procyclical, monetary base perhaps with a slight lag, M1 with no clear phase shift (except for the last few years), and M2 with a lead of a couple of quarters. Velocity is procyclical and highly variable, while both measures of the price level are countercyclical.[1]

In Section 2, the basic business-cycle environment is presented. Its long-run properties are derived and the model economy calibrated in Section 3. The cyclical properties of the model with price surprises are presented in Section 4. Section 5 describes the findings for the model version in which there is a trade-off in household production between real money and leisure. The final section offers some discussion.

2. *A Real Model of Aggregate Fluctuations*

The model can be thought of as a growth model with technology shocks. It includes a time-to-build technology for producing durables. For my purpose, I make these goods consumer durables, although they will play a similar role for some of the model properties as producer durables would have. In other words, the durables affect the ability and willingness to substitute intertemporally.

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, ℓ_i is nonmarket time, and $0 < \beta < 1$ is a discount factor. If past leisure choices are included in current utility, then intertemporal substitution of leisure becomes a more important feature of the environment. The implication is that the more one has worked in the (recent) past, the higher is the disutility of working in period t. An interpretation is that a fraction of 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

$$u(c_t, d_t, \ell_t, \ell_{t-1}, \ldots) = \left[c_t^{\mu} d_t^{\theta} \left\{ \sum_{j=0}^{\infty} \alpha_j \ell_{t-j} \right\}^{1-\mu-\theta} \right]^{1-\gamma} / (1-\gamma),$$

where μ, θ, and γ are given positive parameters, with $\mu + \theta < 1$. The α's are assumed to be such that $0 < \alpha_0 \leq 1$, $\alpha_{j+1}/\alpha_j = 1 - \eta$ for $0 < \eta < 1$ and $j = 1,2,\ldots$, and $\sum_{j=0}^{\infty}\alpha_j = 1$. 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, $n_t + \ell_t = 1$ in every period. Then

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

where $a_t \equiv \sum_{j=1}^{\infty}(1-\eta)^{j-1} n_{t-j}$, 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 substitution 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 relative price.

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 two relations 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

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

Aggregate output is given by $Y_t = \sum_i \lambda_{it} n_{it}$, where λ_{it} is the productivity of sector i. In equilibrium, each real wage rate w_{it} will equal the corresponding level of productivity. The budget constraint is

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

where 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 define implicitly the interest rate r_t by $1/(1+r_t) = P_{bt}$.

Suppose now that there is a distribution of individual technology shocks, and that people live on "islands" in the sense suggested by Phelps (1970). 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:

$$\Lambda_t = \rho\Lambda_{t-1} + H + Z_t,$$
$$\lambda_{it} = \Lambda_t + \epsilon_{it}, \quad \forall i.$$

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

Laws of motion analogous to those of individual variables govern also the aggregate or per capita quantities D_t, X_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, plays a role when computing the equilibrium of models in which the equilibrium is not simply the solution to a stand-in planner's problem. In particular, this is true in models with government policy, in our case monetary policy. The details are in Kydland (1989).

In what follows, I assume that the model structure 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.

3. *Steady State and Calibration*

A great deal of a priori knowledge can be used to place quantitative restrictions on parameters, such as capital-depreciation rates, capital-output ratios, weights on lags in expenditures on durables, elasticity of long-run labor supply, and so on. 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 x = 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, then 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

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

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

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

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 set to 0.05, while that of other household capital produced with nonmarket time as input, η, is set equal to 0.10. Furthermore, we set $\alpha_0 = 0.60$. These values for α_0 and η are consistent with those estimated by Hotz, Kydland, and Sedlacek (1988) using annual panel data.[2] For comparison, in some experiments α_0 is set equal to one, implying a standard time-separable utility function. The value of γ is two, which means more curvature on the utility function than that corresponding to logarithmic utility.

The share of time, 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. From these values, it follows that μ = 0.20 and θ = 0.10. Average Λ (and therefore W) is chosen so that steady-state output is one. The time to build durables, J, is assumed to equal three, and the values of ϕ_1, ϕ_2, and ϕ_3 are one-third. Finally, consistent with the evidence (see e.g. Prescott 1986) that changes in the production function parameter are long-lived, the autocorrelation parameter ρ is set equal to 0.95.

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 computed as described there.

The elements described in this section are the basis for the two model versions used in Sections 4 and 5. I first turn to the model with imperfect information about aggregate and individual real wages due to aggregate price shocks.

4. *Economy With Aggregate Price Shocks*

Suppose that productivity on each island is determined 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 inferences about his own real wage rate, w_{it}, and about the economy-wide real wage, W_t.

To be specific, assume that

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

where P_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 price shock, P_t, to economy-wide productivity, Z_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 is used to 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

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

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

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

where the random variables Z_t, ϵ_{it}, and P_t are independently and normally distributed with means zero and variances σ_Z^2, σ_ϵ^2, and σ_P^2. The notation W_t^e stands for the expected value of W_t, conditionally on observations with index less than t. With these assumptions, we have the following conditional expectations (see Graybill 1961, p. 63)

$$E(W_t|\hat{w}_{it}) = (1-\psi_1)W_t^e + \psi_1\hat{w}_{it}, \quad \text{where } \psi_1 = \sigma_Z^2/(\sigma_Z^2 + \sigma_\epsilon^2 + \sigma_P^2), \text{ and}$$

$$E(w_t|\hat{w}_{it}) = (1-\psi_2)W_t^e + \psi_2\hat{w}_{it}, \quad \text{where } \psi_2 = (\sigma_Z^2 + \sigma_\epsilon^2)/(\sigma_Z^2 + \sigma_\epsilon^2 + \sigma_P^2).$$

The purpose of the computational experiments is to determine the extent to which price surprises, through this information structure, quantitatively affect business cycles. Since the individual cannot distinguish between monetary innovations, P_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.

For the standard case in Table 2, the standard deviations of all three shocks are 0.6 percent. For the aggregate technology shock, this is about four-fifths of the standard deviation estimated by Prescott (1986) based on U.S. quarterly data since 1954. This choice was made because, with capital only in the household and not in the business sector, the contribution of technology shocks to volatility probably is somewhat overstated.

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. One may note that, unlike in Lucas (1972), who did not include economy-wide technology shocks in his model, the island shocks are not necessary in order for the price shocks to have real effects. (This point has been made also by Wallace 1989).

The figures in Table 2 are obtained by drawing 50 independent samples of 144-quarter length, which is the length of the sample period for the U.S. data. For each sample, the cyclical components are calculated using the same method as in Table 1 for the U.S. data. For each statistic, I report the average and the standard deviation of the 50 samples. These are estimates of the means and standard deviations of the sampling distributions of the statistics for the model economy and can be compared with the statistics for the U.S. economy.

We see that the average standard deviation of output is 1.63 percent, while that of hours worked is 1.01 percent. A substantial part of that variability is accounted for by the intertemporally nonseparable utility function. For the time-separable case (α_0=1), the corresponding figures are 1.19 and 0.50 percent.

To assess the extent to which price shocks contribute to real variability, consider a series of experiments such as that in Table 2, except that σ_p is changed in steps of 0.10, holding σ_z and σ_ϵ fixed. The outcome is displayed as the points on the curves labelled I in Figure 4. The percentage standard deviation of cyclical output, σ_y, is greatest when there are no price shocks, although hours variability rises slightly until $\sigma_p = 0.4$. This finding is contrary to the standard view that nominal shocks increase output variability over some range.[3] The intuitive reason for the finding is that, while the effect of a price shock on real variables in the same period is greater the larger that shock is, an increase in the variance of price shocks also reduces the magnitude of the average response to all shocks.

For small values of the standard deviation of the aggregate technology shock, σ_z, still holding σ_ϵ fixed, the relation between σ_y and σ_p is indeed hump-shaped, although it perhaps is surprising how small the σ_p is for which the peak occurs. Curves labeled II in Figure 4 display the case of $\sigma_z = 0.10$.

Of separate interest, perhaps, is the role of the "island" or sector shocks. In Figure 5, the variabilities of the aggregate technology shock and the nominal shock are held fixed ($\sigma_z = \sigma_p = 0.60$), but σ_ϵ is varied in intervals of 0.20. In the low end of this range of variability of the sector shocks, an increase of σ_ϵ increases output volatility substantially, from a standard deviation of 1.41 when $\sigma_\epsilon = 0$ to 1.85 when $\sigma_\epsilon = 1$. At the same time, the cross correlation of output with itself lagged one quarter drops from 0.73 to 0.41, while productivity goes from leading the cycle slightly for low values of σ_ϵ to lagging clearly for large values of σ_ϵ. Along both of these dimensions, then, larger sector-shock volatility leads to greater discrepancies between the model and the data.

Throughout these experiments, the period length was assumed to be one quarter, which therefore is also the duration of each sector shock. Increasing the period length to half a year or a full year changes the numbers, but the general nature of the comparisons remains unaffected.

The main conclusion 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. With aggregate shock variance similar to that obtained from measurements of Solow residuals in the U.S. economy, the output variance drops over the entire range of price-shock variability.

5. *Money as a Medium of Exchange*

In this section, I focus on the role of money in facilitating transactions. A much-used modeling approach is to include a cash-in-advance constraint, which goes so far as to make an equal amount of money a *prerequisite* for a given amount of purchases.[4] While this is a useful abstraction for many purposes, it is an unnecessarily severe constraint, especially when there is also a time-allocation decision as in this model. Moreover, it has proved to be a challenge to get much velocity movement in cash-in-advance models. Instead, I introduce a trade-off in the household between real money and leisure. The idea is that holding more money saves trips to the bank, shopping time, and so on.[5]

Here, I abstract from the island setup, that is, I let σ_ϵ equal zero. The aggregate technology level is known before making decisions in every period.

The government has outstanding a nominal stock of money, m_t, when period t begins.[6] The price of money relative to that of consumption goods is p_t. The budget constraint for the typical individual is

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

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.[7] 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) yields another equation so that we can solve for pm in terms of the given parameters. If the average money stock is fixed, then the steady-state price level p can be determined.

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 (and 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.

The values assumed for ω_0 and ω_1 are 0.0065 and 0.50, respectively. These magnitudes probably can be understood best through a marginal evaluation at the steady-state real money stock, pm. If the real money stock is increased by one percent relative to its steady state, then a household's resulting weekly saving in leisure is less than a minute. Moreover, the implied steady-state velocity is 5.3, which corresponds to average M1 velocity since 1959.

The first question addressed is how much the price level would move with no fluctuation in the money stock. Cyclical statistics from the model economy are presented in Table 3. The statistics for the real variables are close to those from the model in the preceding section for the case in which both sector shocks and price shocks have zero variance. In other words, the monetary shock has an imperceptible effect on the cyclical properties of the real aggregates. The correlation coefficient of the price level (conventionally measured) with GNP is -0.91 and its cyclical standard deviation 0.72. Without the lag in the production of durables, the price fluctuation is somewhat smaller.

When utility is time separable in leisure, the output variation is reduced from 1.49 to 1.17 percent, hours variation from 0.78 to 0.43 percent, and price level variation to 0.67 percent. In other words, output and hours volatilities are substantially reduced with very little reduction in price variability. This finding for the price level makes intuitive sense. In the nonseparable case, the immediate effect on current marginal utility of, say, working one more hour is smaller. Instead, future utility is also adversely affected in a direct way by the increase in current hours of work. Consequently, 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 no money-stock variability, the price fluctuation in this model surely is smaller than that observed in U.S. data. Still, the benchmark of constant money stock (interpreted as constant growth rate) produces more than one-half of the observed price variability. Some fluctuation in the money stock would increase the price fluctuation. The correlations of nominal aggregates 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 0.60 percent, then the standard deviation of the price level increases to 1.13 percent, that of velocity to 1.09 percent, and the contemporaneous correlation coefficient between the conventional price level and output becomes -0.59, which is close to that in the U.S. data.

6. Discussion

The goal of this paper has been to make a contribution toward assessing the quantitative importance of money in a real business cycle model. To this end, two sets of computational experiments were conducted. In the first set, I assume price shocks in a model version that includes temporary sector-specific technology shocks as well as persistent economy-wide shocks. "Island" shocks add some volatility, but the magnitude of the variability of price shocks makes surprisingly little difference to the real aggregates.

In the second set of experiments, I abstract from imperfect information about wage rates. Instead, the focus is on the variability of nominal aggregates and their comovements with the business cycle as defined by cyclical 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 more than half of the price variation observed in the U.S. economy since the Korean War. Adding some monetary shocks conceivably may account for most of the remainder while still being consistent with the observed procyclical velocity and countercyclical price level.

The separate introduction of the two monetary mechanisms helps to isolate their implications. In reality, what may be going on is that economic activity resulting from aggregate technology shocks gives 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 the aggregate price level from moving countercyclically. It is interesting to note, however, that neither one of these mechanisms contributes to any real variability to speak of. With aggregate technology shocks of magnitudes corresponding to those implied by Solow residuals, I find that, for this model environment, larger price-surprise volatility lowers the variability of output.

In addition to the leisure-saving motive at the household level, one could introduce a trade-off between real money and labor in producing output in the firm. Then one could also use information about the 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). They use rental prices of various financial assets to determine measures of the assets' relative liquidity services to be added up.

One especially 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 that are not captured 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 abstracted also 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 more substantial 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 rates. This effect may have been a contributing factor to the slower growth experienced in the 1970s.

Footnotes

[1]The price level has been found to be countercyclical in the postwar period also in other major countries (Backus and Kehoe 1989) and in the U.S. using alternative statistical methods (Cooley and Ohanian 1989).

[2]For these parameter values, the weights on ℓ_t, ℓ_{t-1}, ℓ_{t-2}, ... in the current utility function are 0.600, 0.040, 0.036, ...

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

[4]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.

[5]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. McCallum (1983) argues that 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.

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

[7]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 the amount of velocity and price-level volatility 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

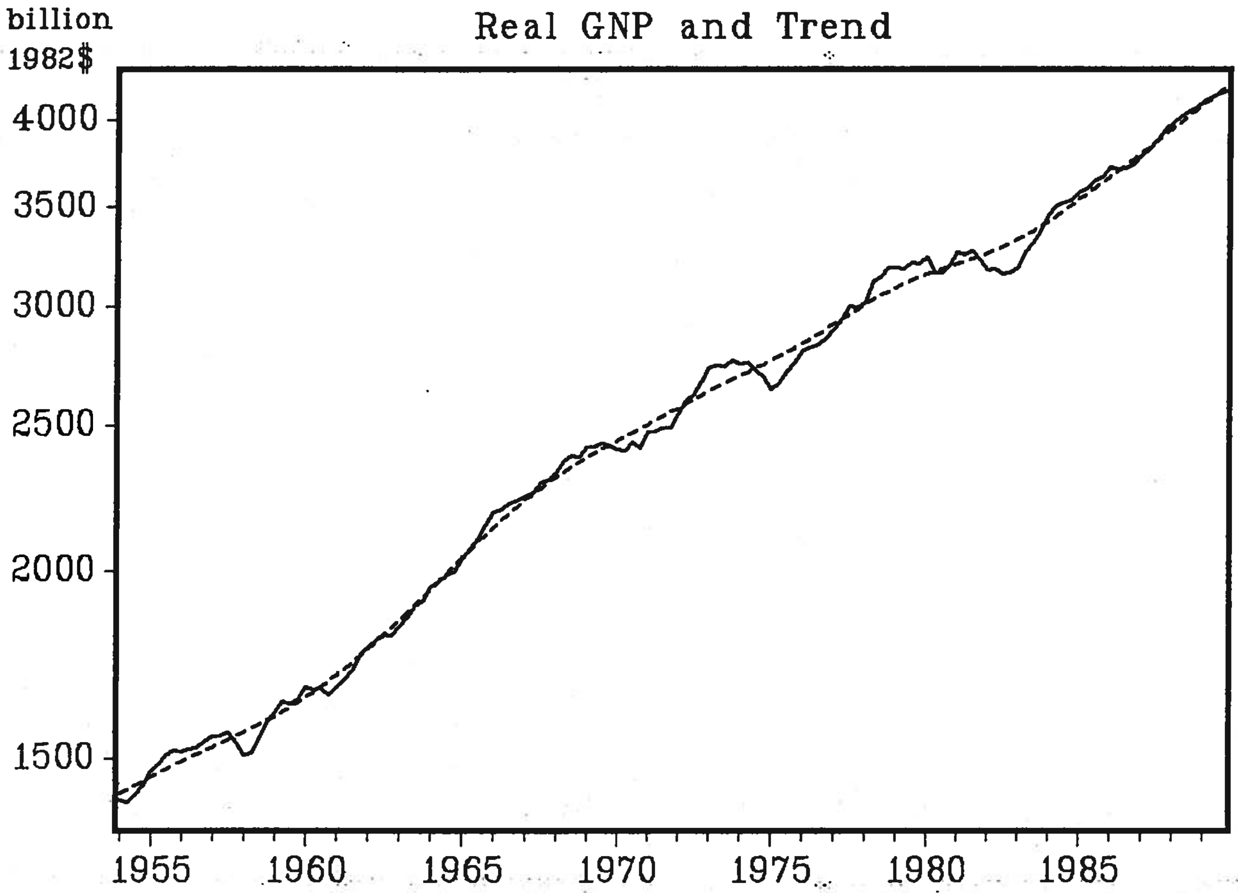

Real GNP and Trend
billion
1982$
4000
3500
3000
2500
2000
1500
1955
1960
1965
1970
1975
1980
1985

Figure 2

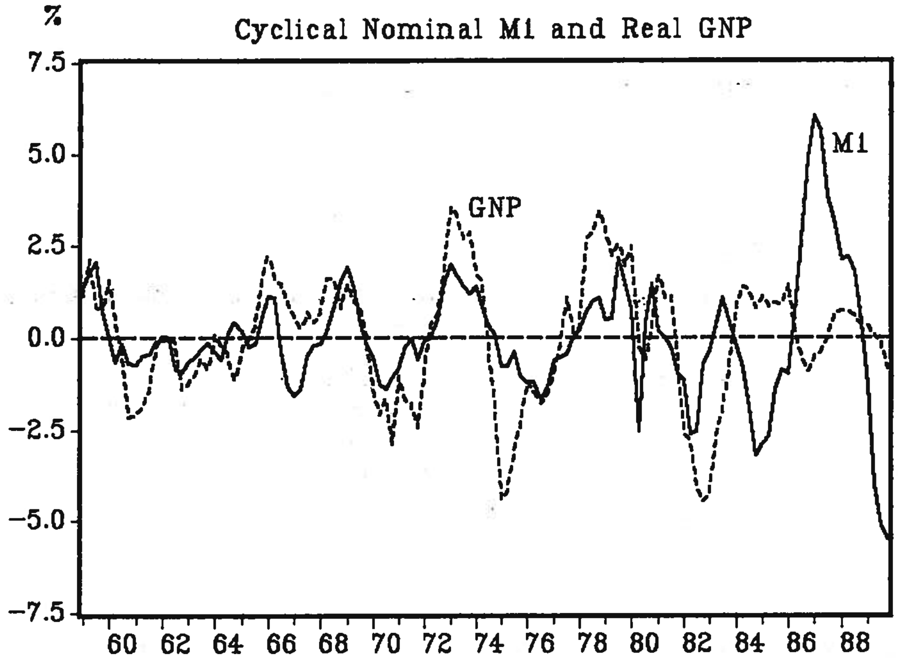


Figure 3

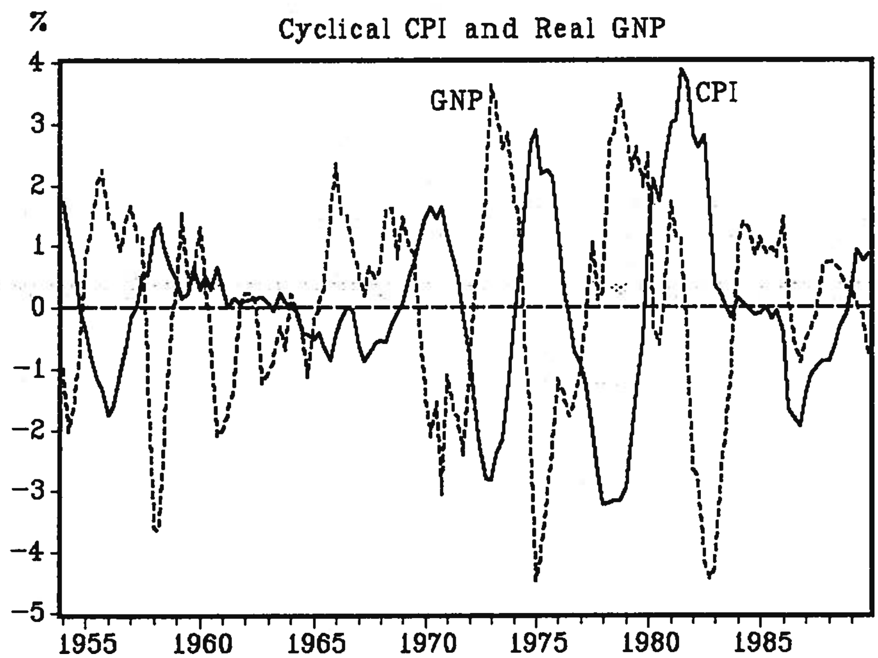
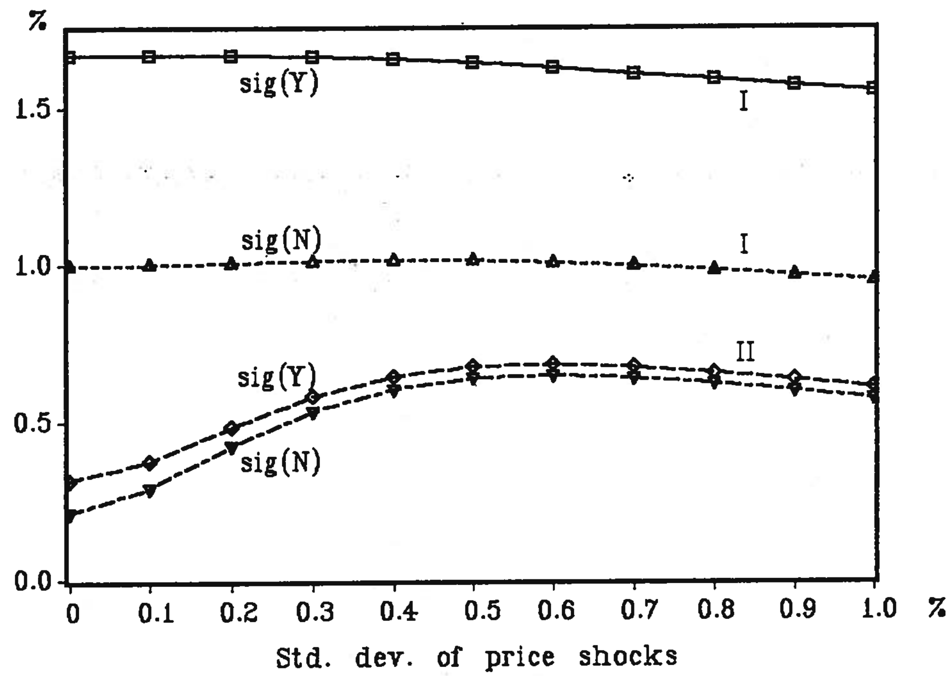


Figure 4

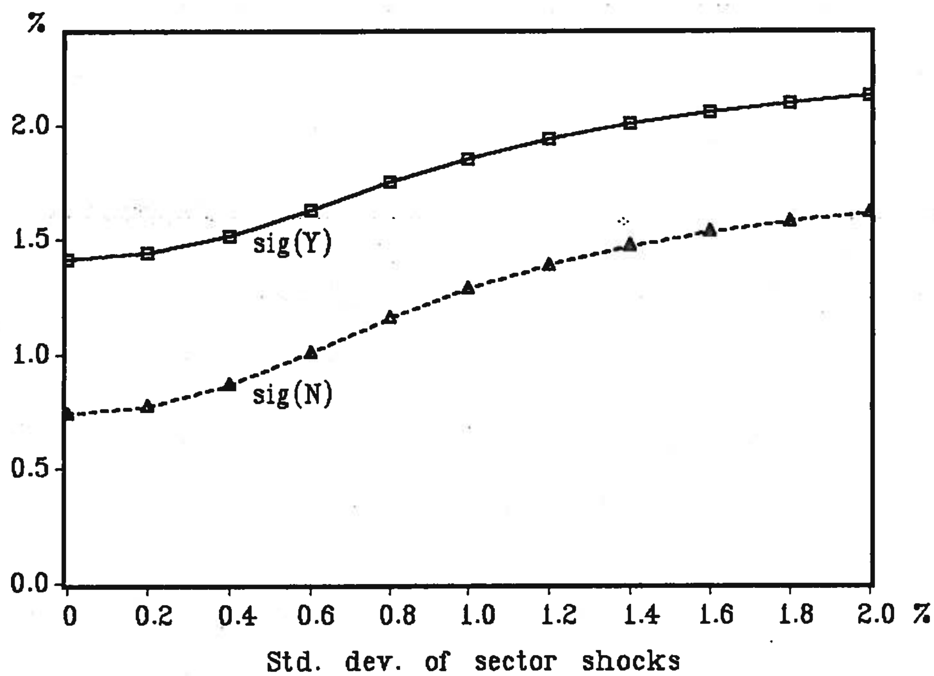


Relation between output and hours variability and price-surprise variability, holding standard deviation of sector productivity shocks constant (0.6 percent).

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 sector-productivity variability, holding standard deviations of aggregate productivity and of price surprises constant (both equal 0.6 percent).

References

Backus, David K., and Kehoe, Patrick J. 1989. International evidence on the historical properties of business cycles. Federal Reserve Bank of Minneapolis Working Paper 402R.

Barro, Robert J. 1978. Unanticipated money growth, output and the price level in the United States. *Journal of Political Economy* 86, 549-580.

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.

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

Cooley, Thomas F., and Ohanian, Lee E. 1989. The cyclical behavior of prices. Forthcoming in *Journal of Monetary Economics*.

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

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

Friedman, Milton, and Schwartz, Anna J. 1963. *A Monetary History of the United States, 1867-1960*. Princeton: Princeton University Press.

Frisch, Ragnar. 1933. Propagation problems and impulse problems in dynamic economics. In *Economic Essays in Honour of Gustav Cassel*. London: Allen and Unwin.

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.

Hansen, Gary D. 1985. Indivisible labor and the business cycle. *Journal of Monetary Economics* 16, 309-327.

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 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,* ed. F. van der Ploeg and A. J. de Zeeuw. Amsterdam: North-Holland.

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. 1980. Equilibrium in a pure currency economy. In *Models of Monetary Economics,* ed. 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.

McCallum, Bennett T. 1989. *Monetary Economics*. New York: Macmillan Publishing Co.

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, 919-44.

Wallace, Neil. 1989. Lucas's signal-extraction model: A finite state exposition with aggregate shocks. Working Paper 313, Federal Reserve Bank of Minneapolis.

Table 1
Cyclical Behavior of the U.S. Economy:
Deviations from Trend of Key Variables, 1954:1-1989:4[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 Components												
Gross National Product	1.71%	-.03	.15	.38	.63	.85	1.00	.85	.63	.38	.15	-.03
Consumption Expenditures												
Services & Nondurable Goods	.84	.20	.38	.53	.67	.77	.76	.63	.46	.27	.06	-.12
Durable Goods	4.99	.25	.38	.50	.64	.74	.77	.60	.37	.10	-.14	-.32
Fixed Investment Expenditures	5.51	.09	.26	.44	.65	.83	.90	.81	.60	.35	.08	-.14
Labor Input												
Hours (Household Survey)	1.47	-.10	.05	.23	.44	.69	.86	.86	.75	.59	.38	.18
Hours (Establishment Survey)	1.65	-.23	-.07	.14	.39	.66	.88	.92	.81	.64	.42	.21
Prices												
GNP Deflator	.89	-.50	-.61	-.68	-.69	-.64	-.55	-.43	-.31	-.17	-.04	.09
CPI	1.41	-.52	-.63	-.70	-.72	-.68	-.57	-.41	-.24	-.05	.14	.30
Monetary Aggregates[b]												
Monetary Base	.88	-.12	.02	.14	.25	.36	.41	.40	.37	.32	.28	.26
M1	1.68	.01	.12	.23	.33	.35	.31	.22	.15	.09	.07	.07
M2	1.51	.48	.60	.67	.68	.61	.46	.26	.05	-.15	-.33	-.46
Velocity[b]												
M1	2.02	-.24	-.19	-.12	-.01	.14	.31	.32	.27	.20	.10	.00

[a]Data Source: Citibase
[b]For the period 1959:1-1989:4

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	1.63	-.11	-.02	.04	.31	.55	1.00	.55	.31	.04	-.02	-.11
	(.13)	(.09)	(.09)	(.06)	(.09)	(.06)	(.00)	(.06)	(.09)	(.09)	(.09)	(.09)
Nondurable Consumption	.68	-.19	-.11	-.06	.25	.52	.95	.60	.41	.25	.12	.02
	(.06)	(.08)	(.08)	(.08)	(.08)	(.05)	(.01)	(.06)	(.09)	(.10)	(.11)	(.11)
Durables Expenditures	3.96	-.07	.02	.08	.32	.54	.99	.51	.26	-.05	-.07	-.15
	(.30)	(.10)	(.10)	(.10)	(.10)	(.06)	(.001)	(.06)	(.09)	(.09)	(.09)	(.09)
Hours	1.01	-.03	.04	.07	.30	.47	.94	.40	.17	-.12	-.11	-.18
	(.07)	(.10)	(.10)	(.10)	(.10)	(.07)	(.01)	(.07)	(.09)	(.08)	(.08)	(.08)

[a]These are the means of 50 histories, each of which was 144 periods long. The numbers in parentheses are standard deviations.

Table 3

Cyclical Behavior of Economy with Money-Leisure Trade-Off[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	1.49 (.13)	-.13 (.10)	-.02 (.10)	.10 (.10)	.38 (.08)	.67 (.05)	1.00 (.00)	.67 (.05)	.38 (.08)	.10 (.10)	-.02 (.10)	-.13 (.10)
Nondurable Consumption	.65 (.06)	-.23 (.08)	-.13 (.08)	-.01 (.08)	.29 (.06)	.61 (.04)	.96 (.01)	.70 (.05)	.48 (.08)	.30 (.10)	.14 (.12)	.02 (.12)
Durables Expenditures	3.54 (.30)	-.09 (.11)	.02 (.11)	.15 (.10)	.40 (.08)	.68 (.05)	.99 (.001)	.65 (.04)	.33 (.07)	.02 (.07)	-.09 (.09)	-.19 (.09)
Hours	.78 (.06)	-.05 (.12)	.06 (.11)	.19 (.10)	.42 (.08)	.68 (.05)	.97 (.005)	.61 (.04)	.27 (.06)	-.07 (.08)	-.16 (.08)	-.25 (.08)
Price Level	.72 (.07)	.27 (.08)	.17 (.08)	.08 (.08)	-.24 (.06)	-.57 (.04)	-.91 (.01)	-.68 (.05)	-.50 (.08)	-.38 (.10)	-.21 (.12)	-.09 (.12)
Velocity	.89 (.07)	.00 (.12)	.10 (.12)	.23 (.10)	.43 (.08)	.67 (.05)	.94 (.01)	.58 (.04)	.23 (.06)	-.14 (.07)	-.21 (.07)	-.30 (.07)

[a]These are the means of 50 histories, each of which was 144 periods long. The numbers in parentheses are standard deviations.