IHS Economics Series
Working Paper 42
March 1997

Unanticipated Money

Thomas F. Cooley
Gary D. Hansen

Impressum

Author(s):
Thomas F. Cooley, Gary D. Hansen

Title:
Unanticipated Money

ISSN: Unspecified

1997 Institut für Höhere Studien - Institute for Advanced Studies (IHS)
Josefstädter Straße 39, A-1080 Wien
E-Mail: office@ihs.ac.at
Web: www.ihs.ac.at

Institut für Höhere Studien (IHS), Wien
Institute for Advanced Studies, Vienna

Reihe Ökonomie / Economics Series **No. 42**

Unanticipated Money

Thomas F. Cooley, Gary D. Hansen

Unanticipated Money

Thomas F. Cooley, Gary D. Hansen

Reihe Ökonomie / Economics Series No. 42

March 1997

Thomas F. Cooley
Department of Economics
University of Rochester
Harkness Hall
Rochester, NY 14627-0156, U.S.A.
Phone: ++1/716/275-8380
e-mail: cooleyto@mail.ssb.rochester.edu

Gary D. Hansen
Department of Economics
University of California, Los Angeles
2263 Bunche Hall
Box 951477
Los Angeles, CA 90095-1477, U.S.A.
Phone: ++1/310/825-3847
Fax: ++1/310/825-9528
e-mail: ghansen@econ.ucla.edu

Institut für Höhere Studien (IHS), Wien
Institute for Advanced Studies, Vienna

The Institute for Advanced Studies in Vienna is an independent center of postgraduate training and research in the social sciences. The **Economics Series** presents research done at the Economics Department of the Institute for Advanced Studies. Department members, guests, visitors, and other researchers are invited to contribute and to submit manuscripts to the editors. All papers are subjected to an internal refereeing process.

Abstract

The role of unanticipated changes in money growth for aggregate fluctuations is reexamined using the methods of quantitative equilibrium business cycle theory. A stochastic growth model with money is constructed that has the feature, following Lucas (1972, 1975), that production and trade take place in spatially separated markets (islands). Individuals must infer changes in the aggregate price level from observing local relative prices. This causes individuals to react to changes in the average price level, due to unanticipated changes in the aggregate money supply, as though they were changes in market specific relative prices. We show that this mechanism can lead to quantitatively large fluctuations in real economic activity. The statistical properties of these fluctuations, however, are quite different from the properties of fluctuations observed in the U.S. economy.

Keywords

Business cycles, monetary policy, aggregate fluctuations, real business cycles

JEL-Classifications

E32, E52

Comments
This paper has been prepared for a conference on the “Dynamic Effects of Monetary Policy,” held at the Federal Reserve Bank of Cleveland in November 1996. We acknowledge helpful comments on previous versions from David Altig, Satyajit Chatterjee, Russell Cooper, Paul Gomme, and Tryphon Kollintzas.

1. Introduction

In Lucas (1972), an economy is described in which unanticipated increases in the money growth rate leads to increases in the level of employment and output. This idea was extended in Lucas (1975) to a neoclassical growth economy with capital accumulation and modern equilibrium business cycle theory was born. The results obtained in that paper, however, were only qualitative in nature. Later, Kydland and Prescott (1982) described a methodology for obtaining quantitative results from equilibrium business cycle models, and these techniques are now standard in the theoretical literature on aggregate fluctuations. However, the model that Kydland and Prescott studied is one in which the impulses that lead to business cycles are shocks to technology rather than changes in the growth rate of money. The purpose of the current paper is to reexamine the idea of Lucas (1972, 1975) using the methods of quantitative equilibrium business cycle theory. Our goal is to use Lucas's model to study the importance of monetary shocks for fluctuations in real variables in the same sense that the real business cycle literature studies the importance of technology shocks.

This is not the first attempt to study the quantitative implications of the Lucas story. Kydland and Prescott (1982), Kydland (1989) and Cooley & Hansen (1995) all describe economies which attempt to capture the central feature of the islands model using a technology shock that is observed with noise. Agents face a signal extraction problem, as they do in the Lucas model, and the noise is only informally interpreted as resulting from monetary policy. Those studies found that noise shocks have only a small effect on output fluctuations. In this paper we are explicit about the role of money and the role of island-specific shocks. Our findings suggest that the conclusions of those earlier papers were misleading.

The economy we study is a close relative of the cash-in-advance economy studied in Cooley and Hansen (1995). In that model, changes in the growth rate of money affect real variables only to the extent that they signal changes in the inflation tax. That is, increases in the growth rate of money lead agents to expect higher inflation in the future. In response to this, agents substitute away from activities that involve the use of cash in favor of activities that do not require cash. The model studied in this paper introduces an additional monetary non-neutrality: agents confuse changes in the economy wide price level with changes in a market specific relative price. This is because agents are only able to observe the market price; they can not observe (or accurately infer) the economy wide average price level. This leads perfectly rational agents to confuse money shocks with market specific demand shocks and respond to the former as though they were the latter.

In the next section, we describe the details of this model. In the third section, we discuss our findings. Some brief concluding comments are provided in section 4.

2. The Model Economy

In this section we describe three model economies. The first is a real business cycle model with money introduced by imposing a cash-in-advance constraint. The model is similar to the one studied in Cooley and Hansen (1995) except that agents live in spatially separated markets, or islands, and newly printed money is distributed unequally across these islands. The second economy, discussed in section 2.2, is a linear quadratic approximation of the first economy. Finally, in section 2.3, we incorporate informational asymmetries of the sort described in the introduction to the linear-quadratic economy. Computational tractability is our reason for forming a linear-quadratic approximate economy before introducing informational asymmetries. We perform quantitative experiments with the latter economy in section 3.

2.1. A Cash-in-Advance Economy with Spatially Separated Markets

We consider a world consisting of a large number of spatially separated markets (islands) with measure 1 households per island with identical preferences and initial endowments. Each household is composed of a shopper-worker pair, as in Lucas and Stokey (1987). These agents, who live forever, choose consumption and work effort to maximize expected discounted lifetime utility,

$$E\sum_{t=0}^{\infty}\beta^t[\alpha\log c_{1t}+(1-\alpha)\log c_{2t}-\gamma h_t],\quad 0<\beta<1 \text{ and } 0<\alpha<1. \tag{1}$$

Utility each period depends on consumption of a "cash good" (c_1), consumption of a "credit good" (c_2), and hours worked, h. Households are endowed with one unit of time that can be allocated to work or leisure. The fact that hours worked enters linearly in the utility function follows from the following assumptions: labor is indivisible, utility is separable in consumption and leisure, and agents trade employment lotteries [see Hansen (1985) or Rogerson (1988)]. The two consumption goods, which are produced using the same technology, differ in that previously accumulated cash balances are needed to purchase c_1 but not c_2.

A typical household begins period t with m_t units of cash and k_t units of capital carried over from the previous period. Although production using the household's capital and labor is carried out on the home island, purchases of goods must be made elsewhere. In particular, the shopper, who carries along the household's cash, is randomly assigned to another market to purchase c_{1t}, c_{2t} and investment goods, i_t. The shopper's purchases of c_{1t} are subject to the following cash-in-advance constraint:

$$\tilde{P}_t c_{1t} \le m_t\,, \tag{2}$$

where $\tilde{P}_t$ is the price of output on the island visited.

Credit goods (c_{2t} and i_t) can be purchased using income earned from labor and capital during the same period since payment is not made until the end of the period. Hence, the budget constraint faced by a representative household in period t is the following:

$$\tilde{P}_t(c_{1t} + c_{2t} + i_t) + m_{t+1} \leq P_t(w_t h_t + r_t k_t) + m_t \ . \qquad (3)$$

Output, Y_t, on the representative island is produced using a constant returns to scale technology, where K_t and H_t are the island's per capita stock of capital and hours worked, respectively:

$$Y_t = e^{z_t} K_t^{\theta} H_t^{1-\theta}, \qquad 0 < \theta < 1. \qquad (4)$$

The variable z_t is a shock to technology that is common across all islands and observed at the beginning of period t. It is assumed to evolve according to the law of motion,

$$z_{t+1} = \rho_1 z_t + \varepsilon_{t+1}^1 \quad 0 < \rho_1 < 1. \qquad (5)$$

The random variable ε^1 is i.i.d. normal with mean zero and standard deviation σ_1. Since the production function displays constant returns to scale, the number of firms does not matter. Hence, we can assume, without loss of generality, that there is one firm per island.

Capital is assumed to depreciate at the rate δ each period and one unit of investment yields one unit of capital the following period. Hence, the island's capital stock evolves according to,

$$K_{t+1} = (1-\delta)K_t + I_t, \quad 0 < \delta < 1 \ , \qquad (6)$$

where I_t is the per capita investment on the island.

The equilibrium real wage rate and rental rate will equal the marginal product of labor and capital, respectively. Hence, we obtain the following equilibrium pricing functions:

$$w(z_t, K_t, H_t) = (1-\boldsymbol{q})e^{z_t}\left(\frac{K_t}{H_t}\right)^{q} \quad \text{and}$$
$$r(z_t, K_t, H_t) = \boldsymbol{q}\, e^{z_t}\left(\frac{H_t}{K_t}\right)^{1-q} \qquad (7)$$

Monetary Policy

The economy wide money supply, $\mathbf{M}_t$, grows at the rate $m + g_t$ and new money is introduced at the beginning of period *t*. That is,

$$\mathbf{M}_{t+1} = e^{m+g_t}\mathbf{M}_t \text{ , where} \qquad (8)$$

$$g_{t+1} = \boldsymbol{r}_2 g_t + \boldsymbol{e}^2_{t+1}, \quad 0 < \boldsymbol{r}_2 < 1. \qquad (9)$$

The random variable $\boldsymbol{e}^2$ is i.i.d. normal with mean zero and standard deviation s_2.

Seignorage can be used by the government to finance government spending or to finance lump sum transfers to shoppers. That is,

$$G_t + T_t = \mathbf{M}_{t+1} - \mathbf{M}_t \text{ ,}$$

where G_t and T_t are *per capita* nominal government spending and lump sum transfers, respectively. Government spending and transfers, however, differ from island to island depending on the realization of a market specific shock, s_t. That is, $G_t = \int G_t(s)d\boldsymbol{j}(s)$ and $T_t = \int T_t(s)d\boldsymbol{j}(s)$, where $\boldsymbol{j}(s)$ is the invariant distribution function of the random variable *s* across markets. The functions $G_t(s)$ and $T_t(s)$ are nominal government spending on island *s* and nominal lump sum cash transfers to shoppers visiting island *s*, respectively. In the experiments carried out in this paper, we assume that $T_t(s) = 0$ for all *t* and that,

$$G_t(s_t) = e^{s_t}\mathbf{M}_{t+1} - \mathbf{M}_t \ .^{1} \qquad (10)$$

The shock s_t evolves according to the following autoregressive process:

$$s_{t+1} = \boldsymbol{r}_3 s_t + \boldsymbol{e}^3_{t+1}\,, \quad 0 < \boldsymbol{r}_3 < 1, \qquad (11)$$

where $\boldsymbol{e}^3$ is i.i.d. normal with mean 0 and standard deviation s_3.[2] This implies that the invariant distribution of s across markets (denoted above by the function $\boldsymbol{j}(s)$) is normal with mean 0 and variance $\frac{\boldsymbol{s}_3^2}{1-\boldsymbol{r}_3^2}$. At this point we assume that households observe g_t and s_t at the beginning of period t. They do not know which market they will be assigned to for shopping until after all decisions (except the consumption decision) have been made.

When a shopper leaves his home island to go shop in some randomly assigned market, he carries with him all of the household's cash holdings, m_t. From the perspective of the home market, shoppers from other islands arrive bringing their cash with them. Since these shoppers are randomly assigned from all over the economy, the average stock of cash on the island will equal the economy wide per capita stock of money, $\mathbf{M}_t$. In addition, the government spends $G_t(s_t)$ units of cash. Hence, at the end of the period, the per capita stock of money on the island is given by,

$$M_{t+1} = \mathbf{M}_t + G_t(s_t) = e^{s_t}\mathbf{M}_{t+1} = e^{s_t+g_t+m}\mathbf{M}_t \ . \qquad (12)$$

Assuming that the cash-in-advance constraint (1) is binding, implying that all of this cash is used to purchase consumption goods on the island, M_{t+1} will be the per capita stock of money on the island at the beginning of period $t+1$.[3] In this case, the money supply on the home island evolves according to,

$$M_{t+1} = e^{m+g_t+s_t-s_{t-1}} M_t \ . \qquad (13)$$

---

1 We have experimented with introducing money through lump sum transfers and found that it did not affect our findings very much. In addition, as we will see later, using new money only for government spending eliminates the "inflation tax" distortion in this economy. This allows us to focus exclusively on the importance of "unanticipated money."

2 The assumption of normally distributed shocks for the gt and st processes will be exploited in section 2.3 when we introduce information asymmetries to the model.

3 The assumptions made in this paper are not sufficient to guarantee that the cash-in-advance constraint is binding for all realizations of the g and s processes. However, we will be studying the behavior of an "average" agent (or island), for whom all realizations of the s process are equal to zero. For this fictitious agent, the cash-in-advance binds in all realized states.

Defining an Equilibrium

In this complete information version of our economy, agents observe s_t, g_t, and z_t at the beginning of period *t* before making any decisions. Although they do not know the precise characteristics of the island they will be assigned to for shopping, households do know the period *t* conditional distribution of capital and *s* states across the economy. We denote this distribution by the letter Φ. From this they are able to deduce the distribution of prices. Hence, Φ is part of the household's state vector since the distribution of capital across markets will evolve over time.

Before defining an equilibrium, we apply a change of variables so that the certainty version of the economy has a constant steady state. This is required by the numerical methods we use to compute an equilibrium. In particular, we define,

$$\hat{m}_t \equiv \frac{m_t}{M_t}, \quad \hat{\tilde{P}}_t = \frac{\tilde{P}_t}{\tilde{M}_{t+1}}, \quad \hat{P}_t = \frac{P_t}{M_{t+1}} \quad , \qquad (14)$$

where a tilde above a variable indicates that it describes the randomly assigned shopping island.

Using these expressions to eliminate m_t, $\tilde{P}_t$, and P_t from the model, the household's dynamic programming problem, assuming that equations (1) and (3) hold with equality, is

$$v(s_{-1}, s, g, z, \hat{m}, k, K, \Phi) =$$
$$\max_{\hat{m}', k', h} \left\{ \alpha \log c_1 + (1-\alpha) \log c_2 - \gamma h + \beta E v(s, s', g', z', \hat{m}', k', K', \Phi') \right\}$$

$$\begin{aligned}
\text{subject to} \quad & c_1 = \frac{\hat{m} e^{s_{-1}}}{\hat{\tilde{P}} e^{\tilde{s}+m+g}} \\
& c_2 + k' + \frac{\hat{m}'}{\hat{\tilde{P}}} e^{s_t - \tilde{s}_t} = \frac{\hat{P}}{\hat{\tilde{P}}} e^{s_t - \tilde{s}_t} \left(\mathrm{w}(z, K, H) h + \mathrm{r}(z, K, H) k \right) + (1-\delta) k \\
& K' = \mathrm{K}'(s, g, z, K) \\
& H = \mathrm{H}(s, g, z, K) \\
& \hat{P} = \mathrm{P}(s, g, z, K) \\
& \hat{\tilde{P}} = \mathrm{P}(\tilde{s}, g, z, \tilde{K}) \\
& \Phi' = \mathrm{F}(\Phi, g, z)
\end{aligned} \qquad (15)$$

The maximization is also subject to the laws of motion for the exogenous shocks, given by equations (4) (8), and (10). In addition, the functions w and r are defined in equation (6). Note that last period's realization of the market specific shock, s_{-1}, affects the current return but does not enter the agent's decision rules. This is because the value of s_{-1} only affects the value of cash-good consumption. Given that (1) holds with equality, c_1 is determined by decisions made in the *previous* period rather than the current period. In addition, c_2 is determined so that (3) holds with equality. Hence, since c_1 and c_2 are chosen residually, their realization will depend on the characteristics of the randomly assigned shopping island, $\tilde{s}$ and $\tilde{K}$, in addition to the set of state variables.

The last five constraints in (14) represent the household's perceptions of how market variables, which are outside the control of the household, depend on the state of the market. The first of these determines the market specific capital stock for next period, and the second determines *per capita* hours worked in the market. These perceptions are necessary for agents to compute expected future wage and rental rates [see equation (6)]. The third and fourth equations represent the household's knowledge of how prices are determined, both on the home island and on the randomly assigned shopping island. Since islands are identical expect for the realized values of *s* and *K*, the functional form of these two pricing functions are identical. The last equation in (14) gives the law of motion for the joint distribution of $\tilde{s}$ and $\tilde{K}$ as a function of the *economy wide* state variables, *z* and *g*.

In equilibrium, these perceptions must be correct. Hence, we define a *recursive competitive equilibrium* to be a set of household decision rules, $\mathrm{k}'(x)$, $\hat{\mathrm{m}}'(x)$, and h(*x*), where $x = (s, g, z, \hat{m}, k, K, \Phi)$; a set of market decision rules and pricing functions, H(*X*), $\mathrm{K}'(X)$, and P(*X*), where $X = (s, g, z, K, \Phi)$; and a law of motion for the distribution function Φ, $\mathrm{F}(\Phi, g, z)$ such that:

(*i*) Households optimize. Given the market specific decision rules and pricing functions, $\mathrm{k}'(x)$, $\hat{\mathrm{m}}'(x)$, and h(*x*) solve the household's dynamic programming problem (14).

(*ii*) Individual decision are consistent with market outcomes. Since all agents on an island are identical, this implies,

$$\begin{aligned}
&\hat{\mathrm{m}}'(s, g, z, 1, K, K, \Phi) = 1 \\
&\mathrm{k}'(s, g, z, 1, K, K, \Phi) = \mathrm{K}'(s, g, z, K, \Phi) \\
&\mathrm{h}(s, g, z, 1, K, K, \Phi) = \mathrm{H}(s, g, z, K, \Phi)
\end{aligned}$$

(*iii*) The law of motion $\mathrm{F}(\Phi, g, z)$ must be consistent with the equilibrium law of motion for *K* and the distribution of $\tilde{s}$ across the economy, $j(s)$ [this is the invariant distribution for *s* obtained from (10)].

2.2. A Linear-Quadratic Approximate Economy

Since it is not possible to obtain an analytical characterization of the competitive equilibrium for the above economy, we compute the equilibrium for a linear-quadratic approximation of this model. In addition, the linearity of this equilibrium will make it relatively easy to introduce asymmetric information in the next subsection. The linear-quadratic economy is formed by computing a quadratic approximation of the nonlinear return function in (14), after substituting in the cash-in-advance and budget constraints, eliminating c_1 and c_2.[4] The certainty equivalence property of linear-quadratic models implies that only the first moment properties of probability distributions matter for the solution of the model. Hence, the equilibrium decision rules and pricing functions do not depend on the value of σ_i^2, for i = 1 to 3. In addition, since the mean of $\tilde{s}$ is a constant, we only need to keep track of the mean of $\tilde{K}$ as it evolves over time and can ignore other moments of the distribution function Φ in forming rational expectations of $\tilde{\hat{P}}$. We denote this state variable by **K**, just as we denoted the average stock of money by boldface **M** in equation (7). Rational expectations of $\tilde{\hat{P}}$, when the state is defined in this way, is the same as a rational forecast of the economy-wide average price level, which we denote $\hat{\mathbf{P}}$.

Using this new notation, we can now define a recursive competitive equilibrium for the linear-quadratic economy. The dynamic programming problem solved by households is given by,

$$
\begin{aligned}
&\mathrm{v}(s_{-1}, s, g, z, \hat{m}, k, K, \mathbf{K}) = \\
&\max_{\hat{m}', k', h} \left\{ \mathrm{Q}(s_{-1}, s, g, z, \hat{m}, k, K, \mathbf{K}, \hat{P}, \hat{\mathbf{P}}, \hat{m}', k', h, H) + \beta E\, \mathrm{v}(s, s', g', z', \hat{m}', k', K', \mathbf{K}') \right\} \\
&\text{subject to} \quad s' = \rho_3 s + \varepsilon_3' \\
&\qquad g' = \rho_2 g + \varepsilon_2' \\
&\qquad z' = \rho_1 z + \varepsilon_1' \\
&\qquad K' = \mathrm{K}'(s, g, z, K, \mathbf{K}) \\
&\qquad \mathbf{K}' = \mathbf{K}'(g, z, \mathbf{K}) \\
&\qquad \hat{P} = \mathrm{P}(s, g, z, K, \mathbf{K}) \\
&\qquad \hat{\mathbf{P}} = \mathbf{P}(g, z, \mathbf{K}) \\
&\qquad H = \mathrm{H}(s, g, z, K, \mathbf{K})
\end{aligned}
\tag{16}
$$

4 This quadratic approximation is a Taylor series approximation around the steady state of the certainty version of the model. The certainty version is obtained by setting ε_i (i=1-3) and $\tilde{s}$ equal to zero, and $\tilde{K}$ equal to K. See Hansen and Prescott (1995) for details.

In this problem, the functions v and Q are quadratic and the functions K′, **K′**, P and **P** are linear.

A *recursive competitive equilibrium* for this linear-quadratic economy is a set of linear household decision rules, $\mathrm{k}'(x)$, $\hat{\mathrm{m}}'(x)$, and h(*x*), where $x = (s, g, z, \hat{m}, k, K, \mathbf{K})$; a set of market decision rules and pricing functions, H(*X*), $\mathrm{K}'(X)$, and P(*X*), where $X = (s, g, z, K, \mathbf{K})$; a linear law of motion for the economy-wide average capital stock, $\mathbf{K}'(g, z, \mathbf{K})$; and a function determining the economy-wide average price level, $\mathbf{P}(g, z, \mathbf{K})$, such that:

(*i*) Households optimize. Given the market specific decision rules and pricing function, and the law of motion for the economy-wide average capital stock, $\mathrm{k}'(x)$, $\hat{\mathrm{m}}'(x)$, and h(*x*) solve the household's dynamic programming problem (15).

(*ii*) Individual decision are consistent with market outcomes,

$$\hat{\mathrm{m}}'(s, g, z, 1, K, K, \mathbf{K}) = 1$$
$$\mathrm{k}'(s, g, z, 1, K, K, \mathbf{K}) = \mathrm{K}'(s, g, z, K, \mathbf{K})$$
$$\mathrm{h}(s, g, z, 1, K, K, \mathbf{K}) = \mathrm{H}(s, g, z, K, \mathbf{K})$$

(*iii*) $\mathbf{K}'(g, z, \mathbf{K}) = \mathrm{K}'(0, g, z, \mathbf{K}, \mathbf{K})$ and $\mathbf{P}(g, z, \mathbf{K}) = \mathrm{P}(0, g, z, \mathbf{K}, \mathbf{K})$.

We solve for this recursive competitive equilibrium using the methods described in Hansen and Prescott (1995). The log-linear market decision rules and pricing function obtained for the calibrated version of our economy are shown in Table 2.

2.3 The Economy with Informational Asymmetries

In the model we have been describing, the price of output in the home market, P_t, depends on both the aggregate money growth rate, g_t, and the market specific shock, s_t. If a price increase is due to a change in g_t, it is the result of economy wide inflation and agents will respond to it as a change in the implicit tax rate on money holdings (the "inflation tax"). If a price increase is due to an increase in s_t, then there has been a real increase in the demand for the output of this particular market. Hence, the firm will respond to this increase in the relative price of its output by increasing production. That is, those markets characterized by higher than average nominal government expenditures, *i.e.* a positive value of s_t, will have an above average price. Hence, residents of this island expect, on average, to purchase goods at a lower price than they sell their own output. In addition, if this high level of government spending persists, residents will expect a higher than average return on investment in new capital.

We now introduce informational asymmetries to the linear-quadratic economy defined in the previous subsection. The critical feature of Lucas's (1972, 1975) model, which we now incorporate, is that agents can only observe, and hence make decisions contingent on, the price of output in their own market. They cannot infer the average price level of the economy as a whole.[5] The implication of our informational assumptions is that households are not able to observe the two shocks, g_t and s_t, separately.[6] This introduces the possibility that agents may confuse changes in these two shocks and respond to a change in the economy wide average price level (resulting from a change in g_t) as though it were at least partly a change in the relative price of output in the home market (a change in s_t).

To be more specific, at the beginning of period t, the information set a particular agent uses to form expectations of g_t and s_t, is $I_0 = \{P_j, \tilde{P}_j, j < t\}$.[7] Before any decisions are made, the agent observes P_t, the price of output on his own island. Hence, his information set is now $I_1 = \{P_j, \tilde{P}_{j-1}, j \leq t\}$. After observing this, agents form conditional expectations of s and g, $s_t^e = E(s_t | I_1)$ and $g_t^e = E(g_t | I_1)$. Agents make decisions based on these conditional expectations rather than on direct observations of these two shocks. Hence, the market decision rules and pricing function defined in the previous subsection become $\mathrm{H}(s^e, g^e, z, \hat{m}, k, K, \mathbf{K}^e)$, $\mathrm{K}'(s^e, g^e, z, \hat{m}, k, K, \mathbf{K}^e)$, and $\mathrm{P}(s^e, g^e, z, \hat{m}, k, K, \mathbf{K}^e)$, where $\mathbf{K}^{e\prime} = \mathbf{K}'(g^e, z, \mathbf{K}^e)$ describes how agents' conditional expectations of the economy-wide average stock of capital evolve.[8]

In the remainder of this subsection we describe in greater detail how the conditional expectations s_t^e and g_t^e are computed. From equations (12) and (13), we have that $\ln P_t = m + g_t + s_t - s_{t-1} + \ln M_t + \ln \hat{P}_t$. From this, assuming that they know M_t, individuals can infer a linear function of s_t, g_t, s_{t-1}, $\overline{s}_t^e$, and $\overline{g}_t^e$. The latter two variables represent the market average expectations of the two shocks, which enter the linear function determining $\ln \hat{P}$. This is because $\hat{P}$ is a function of agents *choices* and is therefore a function of expectations and only indirectly a function of actual realized values.

Each agent living on a given island will have different information set. This follows from the fact that each one will have observed a different sequence of $\tilde{P}$'s. However, we are interested in

---

5 In our model, they also observe the price on a randomly assigned shopping island, but we assume this is observed only after all decisions have been made. This information is, however, incorporated into their information set available at the beginning of the subsequent period.

6 There are a large number of households on each island and each one observes a different value of $\tilde{P}_t$. We assume that households are not able to pool this information. If they could, they would be able to infer the economy-wide average price level and hence the value of gt.

7 In practice, to make it easier to compute conditional expectations, we will assume that households observe slightly more than this. They will observe the money supply on the shopping island which they can compare with the money supply on their own island. This will be explained when we describe how we compute agent's conditional expectations.

8 We assume that the economy starts off with all islands being identical. Hence, $\mathbf{K}_0^e = K_0$ for all islands.

solving the problem of the *average* agent living on the *average* island. For this fictitious agent, $\bar{s}_t^e = s_t^e$ and $\bar{g}_t^e = g_t^e$ in equilibrium. Agents have perceptions about how these market average expectations are formed, which must be correct in equilibrium. In particular, they know that these will be a linear function of g_t, s_t, and s_{t-1}. Denote this linear function by $\begin{bmatrix} \bar{g}_t^e \\ \bar{s}_t^e \end{bmatrix} = \mathbf{F} \begin{bmatrix} g_t \\ s_t \\ s_{t-1} \end{bmatrix}$, where **F** is a 2 x 3 matrix to be defined below. Substituting this into the linear function inferred from observing $\ln P$, we obtain a linear function of g_t, s_t, and s_{t-1}, which we denote, $\mathrm{B}(g_t, s_t, s_{t-1}) = \mathbf{B}_1 \begin{bmatrix} g_t \\ s_t \\ s_{t-1} \end{bmatrix}$, where $\mathbf{B}_1$ is a 1 by 3 matrix. This function B represents the incremental information agents receive at the beginning of a period when the information set changes from $I_0 = \{P_j, \tilde{P}_j, j < t\}$ to $I_1 = \{P_j, \tilde{P}_{j-1}, j \le t\}$.

After shopping, households are able to observe $\tilde{P}_t$ and $\ln M_{t+1} - \ln \tilde{M}_{t+1} = s_t - \tilde{s}_t$. That is, agents now observe $\mathbf{B}_2 \begin{bmatrix} g_t \\ s_t \\ s_{t-1} \end{bmatrix} + \boldsymbol{e}_t^4$, where $\boldsymbol{e}_t^4 = -\tilde{s}_t$ and the matrix $\mathbf{B}_2$ is equal to [0 1 0]. The variable $\boldsymbol{e}^4$ is, from the household's point of view, an i.i.d. random variable distributed $N\left(0, \frac{\boldsymbol{s}_3^2}{1 - \boldsymbol{r}_3^2}\right)$. We assume that agents see this rather than simply $\tilde{P}_t$ so that we can abstract from the part of $\tilde{P}$, namely $\hat{\tilde{P}}$, that depends on the conditional expectations of agents on the shopping island. This has the advantage of simplifying the procedure used to compute the conditional expectations of agents on the home island.

Let $e_{0t} = E[x_t | I_{0t}]$ and $\mathbf{V}_{0t}$ be the corresponding conditional covariance matrix, where $x_t = (g_t, s_t, s_{t-1})^T$. Similarly, let $e_{1t} = E[x_t | I_{1t}]$ and $e_{2t} = E[x_t | I_{2t}]$, where $I_{2t} = \{P_j, \tilde{P}_j, j \le t\} = I_{0,t+1}$. In addition, $\mathbf{V}_{1t}$ and $\mathbf{V}_{2t}$ are the corresponding conditional covariance matrices. From equations (8) and (10), we can express the law of motion for *x* as

$$x_{t+1} = \mathbf{A} x_t + \mathbf{E} \begin{bmatrix} \boldsymbol{e}_{t+1}^2 \\ \boldsymbol{e}_{t+1}^3 \end{bmatrix}, \text{ where } \mathbf{A} = \begin{bmatrix} \boldsymbol{r}_2 & 0 & 0 \\ 0 & \boldsymbol{r}_3 & 0 \\ 0 & 1 & 0 \end{bmatrix} \text{ and } \mathbf{E} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}.$$

Given that the e's are normally distributed, the covariance matrices $\mathbf{V}_{0t}$, $\mathbf{V}_{1t}$ and $\mathbf{V}_{2t}$ are constant (over time) matrices that can be obtained from solving the following equations:[9]

$$\mathbf{V_1} = \left(\mathbf{I} - (\mathbf{B}_1\mathbf{V_0})^T(\mathbf{B}_1\mathbf{V_0}\mathbf{B}_1{}^T)^{-1}\mathbf{B}_1\right)\mathbf{V_0}$$

$$\mathbf{V_2} = \left(\mathbf{I} - (\mathbf{B}_2\mathbf{V}_1)^T(\mathbf{B}_2\mathbf{V}_1\mathbf{B}_2{}^T + \frac{\boldsymbol{s}_3^2}{1-\boldsymbol{r}_3^2})^{-1}\mathbf{B}_2\right)\mathbf{V}_1$$

$$\mathbf{V_0} = \mathbf{A}\mathbf{V}_2\mathbf{A}^T + \mathbf{E}\Sigma\mathbf{E}^T \ ,$$

where $\Sigma = \begin{bmatrix} \boldsymbol{s}_2^2 & 0 \\ 0 & \boldsymbol{s}_3^2 \end{bmatrix}$. Applying conditional probability formulas for the multivariate normal distribution, we obtain the following expressions:

$$\begin{aligned} e_{1t} &= \left(\mathbf{B}_1\mathbf{V_0}\right)^T\left(\mathbf{B}_1\mathbf{V_0}\mathbf{B}_1{}^T\right)^{-1}\mathbf{B}_1 x_t + \left(\mathbf{I} - \left(\mathbf{B}_1\mathbf{V_0}\right)^T\left(\mathbf{B}_1\mathbf{V_0}\mathbf{B}_1{}^T\right)^{-1}\mathbf{B}_1\right)e_{0t} \\ e_{2t} &= \left(\mathbf{B}_2\mathbf{V}_1\right)^T\left(\mathbf{B}_2\mathbf{V}_1\mathbf{B}_2{}^T\right)^{-1}\mathbf{B}_2 x_t + \left(\mathbf{I} - \left(\mathbf{B}_2\mathbf{V}_1\right)^T\left(\mathbf{B}_2\mathbf{V}_1\mathbf{B}_2{}^T + \frac{\boldsymbol{s}_3^2}{1-\boldsymbol{r}_3^2}\right)^{-1}\mathbf{B}_2\right)e_{1t} \qquad (17) \\ e_{0,t+1} &= \mathbf{A}\, e_{2t} \end{aligned}$$

Finally, we employ the following procedure in order to solve for the equilibrium value of the matrix **F**; that is, the value of **F** such that $\bar{s}_t^e = s_t^e$ and $\bar{g}_t^e = g_t^e$. Set **F** equal to an arbitrary 2 x 3 matrix and solve for $\mathbf{V}_0$ as described above. Then, using equation (16), we set $\mathbf{F} = (\mathbf{B}_1\mathbf{V}_0)^T(\mathbf{B}_1\mathbf{V}_0\mathbf{B}_1)^{-1}\mathbf{B}_1$ and repeat until successive iterations have converged.

The state variables, g_t^e and s_t^e, are equal to the first two elements of e_{1t}. In our quantitative experiments, we use these variables in place of g_t and s_t in the linear pricing function and decision rules shown in Table 2.

9 For a derivation of these formulas, as well as those in equation (16), see Mood, Graybill and Boes (1974).

3. Quantitative Results

In this section we do three things. First, we describe the calibration of the model. Second, we consider the impulse response of the endogenous variables of the model to a one-standard deviation shock to the money growth rate. For comparison, we also consider the response of the same set of variables to a technology shock. Finally, we present results from three simulation experiments designed to assess the importance of money growth shocks for business cycles. In particular, these experiments enable us to compare the business cycle properties of our model economy with the same properties of postwar U.S. data.

3.1 Calibration

Given that the model studied here is very similar to the cash-in-advance economy presented in Cooley and Hansen (1995), we follow the calibration procedure employed in that paper whenever appropriate. In particular, we chose b, g, q, and d so that the steady state capital-output ratio, investment-output ratio, labor income share, and time spent participating in the labor market are equal to the average of these values computed from U.S. data.[10] Similarly, we employ the same value for a as in our previous paper. In particular, we chose a based on information from a survey of consumer transactions administered by the Federal Reserve Board in 1984 and 1986, which lead us to choose a = .84. According to this survey, 84 percent of consumer transactions are made with cash, if we define cash to be currency, checks, and money orders.

The parameters of the money supply process (m, r_2, and s_2 in equation 8) were assigned values based on estimates from a first order autoregression of the growth rate of M1 (again, see our previous paper for details). The autoregressive parameter of the technology shock process (r_1) was chosen to match the stochastic properties of the Solow residual. In our experiments, we consider alternative values for the standard deviation, s_1.

We do not attempt to calibrate, at least in the usual sense, the parameters of the idiosyncratic shock process, *s*. Given that we do not have much information from actual economies that can be used to calibrate this stochastic process, we chose to calibrate in a way that gives the economy with money growth shocks the best chance of accounting for the business cycle facts. In particular, the autoregressive parameter of this process (r_3 in equation 10) was chosen so as to make the response of the model to aggregate money growth shocks as persistent as possible. By setting r_3 close to 1, agents are driven to produce more and accumulate capital in response to a positive value of e_3 since they expect the good times to persist for a long time. This lead us to choose r_3 = .99.[11] As with s_1, we experiment with

10 See Cooley and Prescott (1995) for details.

11 We chose not to allow s to follow a random walk since this would imply that the standard deviation of $\tilde{s}$ would be infinite. This would mean that agents would learn nothing from observing the price on their assigned shopping island.

alternative values for s_3. The exact values assigned to each of the parameters are given in Table 1.

3.2 Impulse Response Functions

In computing the impulse response functions shown in Figures 1 - 4, we set the standard deviation of innovations to the technology shock process, s_1, equal to 0.00685. This value was chosen because it is the number that enables our model with only technology shocks to explain one hundred percent of the variance in output observed in U.S. time series. Similarly, the standard deviation of innovations to the idiosyncratic process was chosen so that money growth shocks explain all of the variation in output. This lead us to set $s_2 = 0.0048$.

In Figure 1 we show the response of s^e to a one standard deviation shock to aggregate money growth. This shows that it takes agents a large number of periods to learn that the true value of *s* is zero. The half life of the misperceived increase in *s* is about 7 or 8 quarters. Hence, the fact that agents never directly observe *g* and *s* leads to a fair amount of persistence in this model.

We plot the response of real variables to a one standard deviation shock to the money growth rate in Figure 2. Given that the possibility that fluctuations are caused by technology shocks has played such an important role in the recent literature on business cycles, we compare these impulse responses with those of a one standard deviation shock to technology. The most striking difference between the two sets of response functions is that the response to a technology shock lasts longer. However, the shape of these responses are quite similar with the notable exception of the consumption response. In response to a technology shock, both consumption and investment rise. In response to a money shock, agents substitute away from consumption toward investment. Hence, consumption is counter-cyclical in the model with only money shocks.

We conjecture that this follows from the fact that agents believe that, in the future, they will be able to sell output at a higher price than they purchase goods, hence they want to increase investment. However, the relative price of their good has not actually gone up; on average they sell goods for the same price as they pay for them. This means that, on average, the only way these agents can finance increased investment is to give up consumption.

In Figure 3 we show the responses of nominal variables to the same set of shocks. In addition, we compare the response to a misperceived money growth shock with the response to perfectly observed money growth shock. The responses look quite similar in both cases. In particular, the response of the nominal interest rate is exactly the same in both cases. The inflation responses are somewhat different, however. The initial response of inflation to a misperceived money growth shock is almost twice as large at the response to perfectly observed money growth shock.

3.3 Investigating the Business Cycle Properties of the Model Economies

Table 3 presents the business cycle properties of the post-war U.S. economy.[12] Tables 4-6 presents the results of three experiments where the standard deviations of the technology and idiosyncratic shocks are tailored to explore their potential for explaining features of the business cycle. In the first experiment only technology shocks drive fluctuations in output, while in the second monetary shocks are the only source of fluctuations. In each of these experiments, we choose the standard deviation of the respective shocks so that the variance of output from simulations of the model equals the variance computed from U.S. data. As explained above, this implies setting $s_1 = .00685$ and $s_2 = 0.0048$. In the third experiment we include both technology shocks and monetary growth shocks. In particular, we exploit the findings of Kydland and Prescott (1991) and Aiyagari (1994) and choose the standard deviation of shocks so that technology shocks account for about 70% of the fluctuations in output. We then calibrate so that the remainder is due to monetary shocks. This lead us to set $s_1 = .00575$ and $s_2 = 0.00345$ in this experiment.

The results in Table 4 confirm that the islands economy, when driven solely by technology shocks, behaves very much like a standard real business cycle model: it displays business cycle properties that are remarkably similar to the cyclical properties of the U.S. economy. In particular, it matches the real features of the U.S. economy well in most dimensions: consumption is less volatile than output, investment is three and half times as volatile as output, and hours fluctuations are somewhat smaller than those of output. In addition, consumption, investment, hours and productivity are procyclical. Although technology shocks cause fluctuations in some nominal variables, we do not come close to accounting for the size of these fluctuations without introducing monetary shocks.

Table 5 presents the results of the islands economy driven only by monetary shocks. There are several features of these results that are striking. First, it is noteworthy that the islands economy, driven by monetary shocks alone, is capable of producing output fluctuations of the magnitude observed in U.S. business cycles. Monetary shocks of that magnitude, however, produce fluctuations in consumption, investment and hours that are all more volatile than those observed in U.S. data. These shocks also lead to a price level that is twice as volatile as that in U.S. data and an inflation rate that is three times as volatile. Nominal interest rates, however, are still less volatile in this economy than they are in the data. In general, in comparison with the economy driven by technology shocks, this economy exhibits business cycle properties that have less in common with those of the data.

12 Business cycle properties are computed by logging the data (except for series already expressed in percent terms) and applying the Hodrick-Prescott filter. We report the ratio of standard deviations to the standard deviation of output as well as cross correlations with output and the contemporaneous correlation with the money growth rate. The statistics from the artificial economy are averages of 100 simulations of 150 periods each.

Some of the nominal features of the islands economy mimic features of the U.S. economy better than the standard cash-in-advance model [see Cooley and Hansen (1995)]. In the islands economy, inflation, nominal interest rates, and velocity are all procyclical . The price level, however, is also procyclical in contrast to the data.

The most striking failures of this version of the islands economy is the finding that consumption and productivity are counter-cyclical. As explained above, the consumption correlation is a consequence of the way this particular islands economy is structured in that consumption alone has the role of “shock absorber”. When agents are fooled by a monetary shock they have to reduce their consumption in order to increase investment.

Table 6 presents results for the economy driven by both monetary and technology shocks. As in the previous experiment, the relative volatility of real variables with respect to output are too large. The real business cycle properties are, however, closer to those observed in the data than are the results in Table 5. In addition, as in Table 5, there is a positive contemporaneous correlation between output and inflation, interests rates, and velocity. However, the major failings of this as a model of the business cycle remain. Consumption and productivity are counter-cyclical and the price level is procyclical, although not as strongly as in the economy driven only by monetary shocks.

Concluding Comments

Previous attempts, such as Kydland (1989) and Cooley and Hansen (1995), to study the quantitative implications of the Lucas (1972) “islands” economy have reached a pessimistic assessment of the ability of such an economy to produce much in the way of output fluctuations. Our findings suggest this conclusion was somewhat misleading. When the important elements of an islands economy are incorporated, monetary shocks can have powerful real effects and the resulting fluctuations display some (not all) of the real and nominal features of the business cycle.

Clearly the findings contained in this paper indicate that our version of the islands model does not account for the business cycle features of U.S. data as well as a standard real business cycle model. However, we interpret our findings as suggesting that the Lucas model may have been abandoned prematurely. Further experimentation with modified versions of this model economy seem warranted.

References

Aiyagari, S. Rao (1994), "On The Contribution of Technology Shocks to Business Cycles," *Federal Reserve Bank of Minneapolis Quarterly Review*, 18, 22-34.

Cooley, Thomas F. and Gary D. Hansen (1989), "The Inflation Tax in a Real Business Cycle Model," *American Economic Review*, 79, 733-48.

____________________ (1995), "Money and the Business Cycle," in Thomas F. Cooley, ed., *Frontiers of Business Cycle Research*, Princeton: Princeton University Press, 175-216.

Cooley, Thomas F. and Edward C. Prescott (1995), Economic Growth and Business Cycles," in Thomas F. Cooley, ed., *Frontiers of Business Cycle Research*, Princeton: Princeton University Press, 1-38.

Hansen, Gary D. (1985), "Indivisible Labor and the Business Cycle," *Journal of Monetary Economics* 16: 309-328.

Hansen, Gary D. and Edward C. Prescott (1995), "Recursive Methods for Computing Equilibria of Business Cycle Models," in Thomas F. Cooley, ed., *Frontiers of Business Cycle Research*, Princeton: Princeton University Press, 39-64.

Kydland, Finn E. (1989), "The Role of Money in a Business Cycle Model," Institute for Empirical Macroeconomics Discussion Paper 23, Federal Reserve Bank of Minneapolis.

Kydland, Finn E. and Edward C. Prescott (1982), "Time to Build and Aggregate Fluctuations," *Econometrica* 50: 1345-1370.

____________________ (1991), "Hours and Employment Variation in Business Cycle Theory," *Economic Theory* 1, 63-81.

Lucas, Robert E., Jr. (1972), "Expectations and the Neutrality of Money," *Journal of Economic Theory* 4: 103-123.

____________________ (1975), "An Equilibrium Model of the Business Cycle," *Journal of Political Economy* 83: 1113-1144.

____________________ (1977), "Understanding Business Cycles," in Karl Brunner and Alan Meltzer, eds., "*Stabilization of the Domestic and International Economy*, Amsterdam: North Holland.

Lucas, Robert E., Jr. and Nancy L. Stokey (1987), “Money and Interest in a Cash-in-Advance Economy,” *Econometrica* 55: 491-514.

Mood, A.M., F.A. Graybill and D.C. Boes (1974), *Introduction to the Theory of Statistics*, New York: McGraw-Hill.

Rogerson, Richard (1988), "Indivisible Labor, Lotteries and Equilibrium," *Journal of Monetary Economics* 21: 3-16.

Table 1: Parameter Values

β	α	γ	θ	δ	ρ_1	ρ_2	σ_2	ρ_3	μ
0.989	0.84	2.556	0.4	0.019	0.95	0.49	0.0089	0.99	0.015

Table 2: Decision Rules for Full Information Version of Model:

$$\log \hat{P} = 1.62570 - 0.34704\, z + 6.35763\, s + 0\, g - 0.54626 \log K$$

$$\log K' = 0.11324 + 0.12945\, z + 1.21562\, s + 0\, g + 0.96393 \log K$$

$$\log H = -0.02343 + 1.63229\, z + 15.89330\, s + 0\, g - 0.36561 \log K$$

Table 3: Cyclical Properties of U.S. Data

1954:1 - 1991:2

Variable (x)	s_x / s_y	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(1)	x(2)	x(3)	x(4)	x(5)	Correlation with M1 Growth
		Cross-Correlation of Output with:											
Output (y = GNP)	1.0	-.02	.16	.38	.63	.85	1.0	.85	.63	.38	.16	-.02	-.12
Consumption (Non-Durables and Services)	0.50	.22	.40	.55	.68	.78	.77	.64	.47	.27	.06	-.11	.02
Investment (Fixed Investment)	3.10	.08	.25	.43	.63	.82	.90	.81	.60	.35	.09	-.12	-.18
Hours (Household Survey)	.92	-.06	.09	.30	.53	.74	.86	.82	.69	.52	.32	.11	-.15
Price Level (CPI)	.83	-.57	-.66	-.71	-.72	-.65	-.52	-.35	-.17	.02	.19	.34	-.22
Inflation	.33	-.32	-.23	-.10	.01	.19	.34	.43	.44	.47	.43	.34	-.29
Interest Rate (1 Month T-Bill)	.75	-.55	-.41	-.27	-.03	.20	.40	.42	.44	.36	.32	.25	-.27
Money (M1)	.88	.16	.24	.33	.41	.39	.33	.21	.12	.05	.03	.02	.25
Velocity	1.13	-.38	-.33	-.24	-.08	.15	.37	.39	.33	.22	.09	0.0	.01

Table 4:

Experiment 1: Technology Shocks Only

$s_1 = 0.00685$ and $s_2 = 0$

Cross Correlation of Output with:

Variable (x)	s_x / s_y	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(1)	x(2)	x(3)	x(4)	x(5)
Output (y)	1.000	-0.031	0.085	0.242	0.445	0.693	1	0.693	0.445	0.242	0.085	-0.031
Consumption	0.218	-0.303	-0.2	-0.045	0.17	0.451	0.815	0.728	0.63	0.522	0.415	0.316
Investment	3.552	0.021	0.134	0.284	0.476	0.707	0.989	0.655	0.39	0.177	0.018	-0.096
Capital Stock	0.231	-0.504	-0.489	-0.439	-0.346	-0.196	0.022	0.312	0.5	0.604	0.643	0.633
Hours	0.830	0.041	0.154	0.302	0.491	0.716	0.99	0.644	0.371	0.155	-0.007	-0.121
Productivity	0.215	-0.307	-0.202	-0.045	0.175	0.462	0.833	0.741	0.639	0.528	0.419	0.319
Price Level	0.215	0.307	0.202	0.045	-0.175	-0.462	-0.833	-0.741	-0.639	-0.528	-0.419	-0.319
Inflation	0.130	-0.114	-0.175	-0.259	-0.359	-0.467	-0.602	0.152	0.166	0.18	0.177	0.166
Nominal Interest Rate	0.000											
Money Growth Rate	0.000											
Real Balances	0.215	-0.307	-0.202	-0.045	0.175	0.462	0.833	0.741	0.639	0.528	0.419	0.319
Velocity	0.830	0.041	0.154	0.302	0.491	0.716	0.99	0.644	0.371	0.155	-0.007	-0.121

Table 5:

Experiment 2: Monetary Shocks Only

$s_1 = 0$ and $s_2 = 0.0048$

Cross Correlation of Output with:

Variable (x)	s_x / s_y	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(1)	x(2)	x(3)	x(4)	x(5)	Correlation with Money Growth
Output (y)	1.000	-0.079	0.048	0.212	0.427	0.71	1	0.71	0.427	0.212	0.048	-0.079	.723
Consumption	1.339	-0.096	-0.209	-0.344	-0.513	-0.728	-0.912	-0.429	-0.102	0.095	0.215	0.291	-.917
Investment	7.136	-0.011	0.112	0.267	0.466	0.725	0.979	0.653	0.347	0.122	-0.042	-0.162	.768
Capital Stock	0.420	-0.498	-0.494	-0.449	-0.356	-0.199	0.039	0.348	0.547	0.644	0.667	0.638	-.423
Hours	1.677	0.005	0.129	0.284	0.482	0.737	0.986	0.648	0.334	0.104	-0.062	-0.184	.788
Productivity	0.712	-0.121	-0.237	-0.371	-0.536	-0.74	-0.92	-0.529	-0.188	0.052	0.215	0.324	-.842
Price Level	1.550	-0.184	-0.062	0.105	0.332	0.637	0.972	0.815	0.583	0.368	0.186	0.036	.558
Inflation	1.013	0.134	0.192	0.26	0.349	0.464	0.505	-0.237	-0.35	-0.327	-0.28	-0.235	.944
Nominal Interest Rate	0.540	0.119	0.206	0.309	0.44	0.609	0.723	0.068	-0.21	-0.298	-0.309	-0.295	1.00
Money Growth Rate	0.533	0.119	0.206	0.309	0.44	0.609	0.723	0.068	-0.21	-0.298	-0.309	-0.295	1.00
Real Balances	0.712	-0.121	-0.237	-0.371	-0.536	-0.74	-0.92	-0.529	-0.188	0.052	0.215	0.324	-.842
Velocity	1.677	0.005	0.129	0.284	0.482	0.737	0.986	0.648	0.334	0.104	-0.062	-0.184	.788

Table 6

Experiment 3: Both Money and Technology Shocks

$s_1 = 0.00575$ and $s_2 = 0.00345$

Cross Correlation of Output with:

Variable (x)	s_x / s_y	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(1)	x(2)	x(3)	x(4)	x(5)	Correlation with Money Growth
Output (y)	1.000	-0.05	0.062	0.221	0.433	0.692	1	0.692	0.433	0.221	0.062	-0.05	.414
Consumption	0.939	-0.091	-0.125	-0.174	-0.233	-0.302	-0.349	-0.075	0.079	0.159	0.192	0.2	-.935
Investment	4.884	-0.001	0.102	0.246	0.436	0.668	0.932	0.611	0.345	0.136	-0.016	-0.118	.627
Capital Stock	0.296	-0.471	-0.463	-0.42	-0.334	-0.19	0.023	0.31	0.492	0.587	0.615	0.596	-.309
Hours	1.151	0.015	0.118	0.26	0.447	0.673	0.93	0.599	0.326	0.114	-0.038	-0.14	.648
Productivity	0.423	-0.153	-0.169	-0.184	-0.194	-0.199	-0.169	0.001	0.131	0.21	0.25	0.263	-.780
Price Level	1.303	-0.117	-0.073	-0.003	0.097	0.235	0.393	0.358	0.271	0.178	0.097	0.031	.458
Inflation	0.796	0.054	0.075	0.117	0.167	0.228	0.262	-0.057	-0.14	-0.152	-0.134	-0.111	.960
Nominal Interest Rate	0.538	0.058	0.097	0.16	0.239	0.335	0.414	0.049	-0.106	-0.162	-0.167	-0.153	1.00
Money Growth Rate	0.532	0.058	0.097	0.16	0.239	0.335	0.414	0.049	-0.106	-0.162	-0.167	-0.153	1.00
Real Balances	0.423	-0.153	-0.169	-0.184	-0.194	-0.199	-0.169	0.001	0.131	0.21	0.25	0.263	-.780
Velocity	1.151	0.015	0.118	0.26	0.447	0.673	0.93	0.599	0.326	0.114	-0.038	-0.14	.648

Figure 1: Perceived Island Specific Shock in Response to a Money Growth Shock

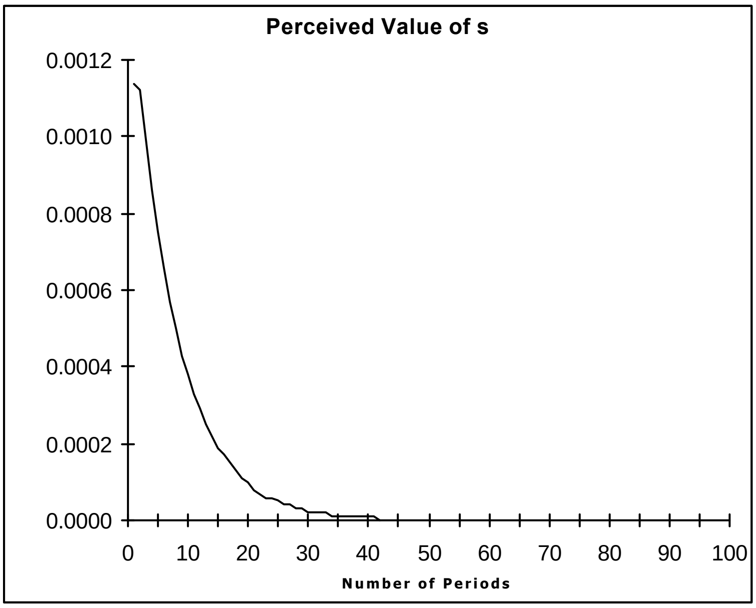


Figure 2: Response of Real Variables to Various Shocks

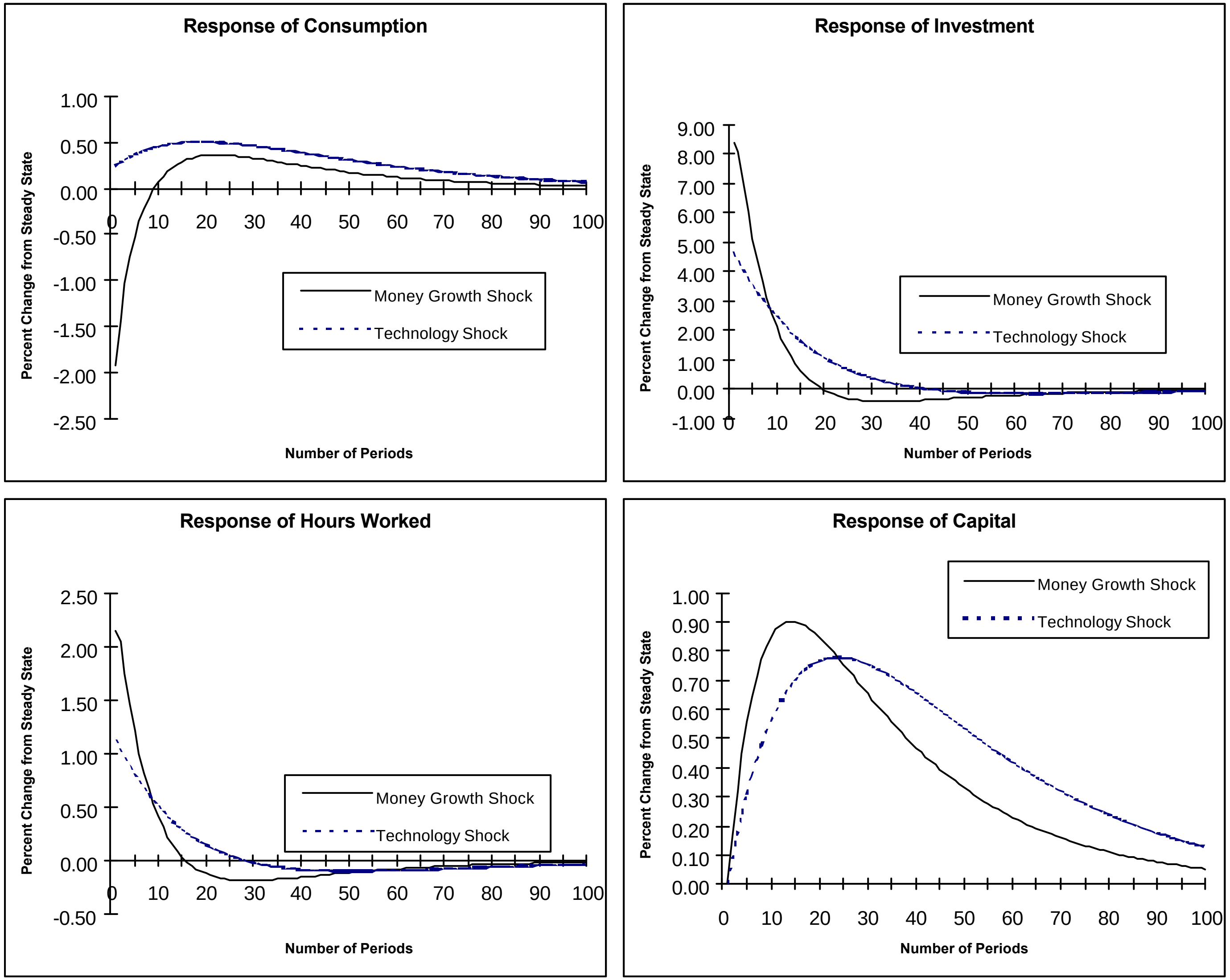


Figure 2 - Continued

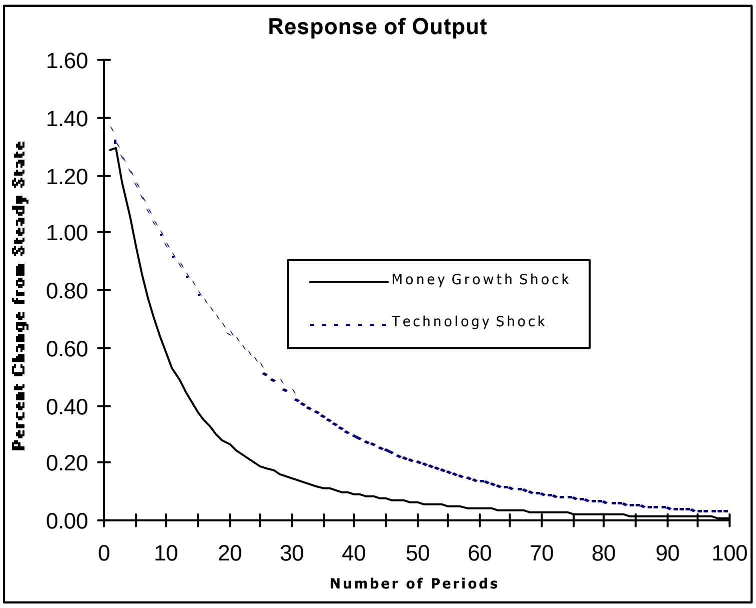
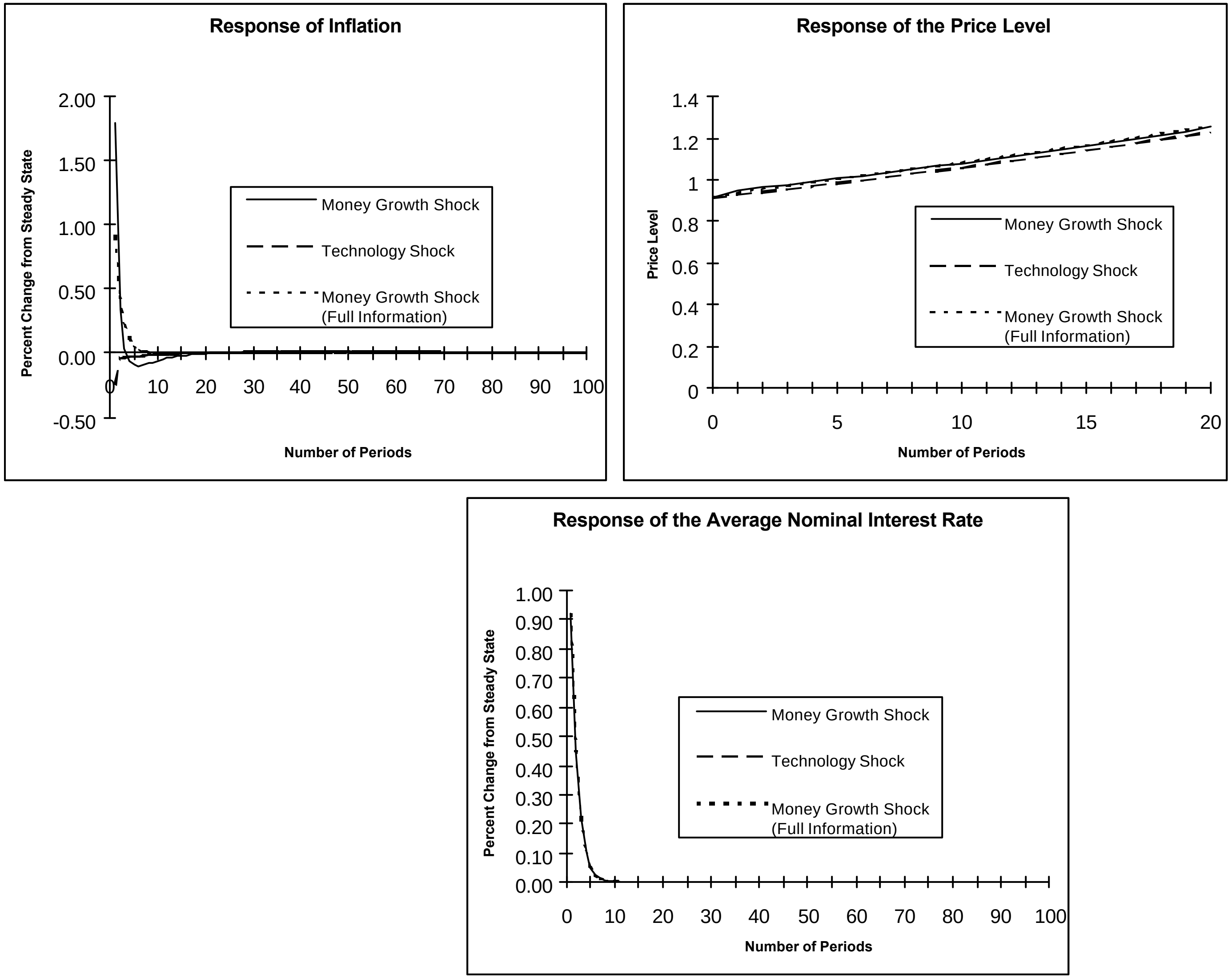


Figure 3: Response of Nominal Variables to Various Shocks



Institut für Höhere Studien
Institute for Advanced Studies
Stumpergasse 56
A-1060 Vienna
Austria

Phone: +43-1-599 91-145
Fax: +43-1-599 91-163