HOW BIG IS THE TIME CONSISTENCY PROBLEM IN MONETARY POLICY?

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VERY PRELIMINARY!

1. Introduction

Many countries have gone through prolonged periods of costly, high inflation, as well as prolonged periods of low inflation. The United States and other industrialized countries went through a high inflation episode during the Great Inflation of the 1970s and are now in a low inflation episode. A central question in monetary economics is why high inflation episodes occurred and what can be done to prevent them from occurring again. One view, advanced by Calvo (1978), Kydland and Prescott (1977) and Barro and Gordon (1983), is that these episodes are a consequence of poorly designed institutions, in the sense that monetary authorities cannot commit to future policies. These authors and others argued that lack of commitment is a problem because when monetary policy is made without commitment there is an *inflation bias*: inflation rates without commitment are higher than they are under commitment. That is, there is a time inconsistency problem in monetary policy.

We call the idea that time inconsistency accounts for the observed inflation episodes, the *inflation bias hypothesis*.[4] If this hypothesis is correct, it is important to redesign monetary institutions towards obtaining greater commitment.[5] The purpose of this paper is to take some preliminary steps towards testing the inflation bias hypothesis. We propose to test the inflation bias hypothesis by incorporating the basic insights of Calvo, Kydland-Prescott and Barro-Gordon into quantitative,

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[4]See Cochrane (1998), Sargent (1999), Taylor (1999) and Woodford (1998) for alternative explanations. See McCallum (1997) for a critique of the proposition that time inconsistency plays a significant role in the dynamics of observed inflation.

[5]See Persson and Tabellini (1993) and Svensson (1995) for examples of possible institutional changes.

general equilibrium monetary models.[6] We wish to understand to what extent such models can account for the dynamics of macroeconomic variables like inflation, output and employment in the data. If such models can account for the dynamics of these variables, then we will have greater confidence that past episodes of high inflation were a consequence of a lack of commitment in monetary policy. The framework can then be used to analyze the consequences of reforming monetary institutions so as to increase the extent of commitment.

In this paper we analyze versions of Lucas and Stokey (1983)'s cash-credit good model. We study these models' implications for the inflation bias. In the models, the benefit of unexpected growth in the money supply is a rise in output and the cost is the misallocation of resources arising from a distortion in relative prices. The monetary authority optimally balances the benefit and costs. In our benchmark model, we obtain the following two results:

- for a surprisingly large range of parameter values, there is an equilibrium in which there is no inflation bias.
- in our model there are at least two equilibria, if there are any.

To put our findings into context, we begin with a summary of the existing literature on the inflation bias hypothesis, which is based on developments of the Barro-Gordon and Kydland-Prescott models. That literature models the private economy's response to the actions by the monetary authority as a reduced form relationship. Similarly, a reduced form expression is used to characterize the policymaker's objectives. The policymaker is viewed as balancing the benefits and costs associated with unanticipated money injections. The costs associated with a marginal increase in inflation are modeled as monotonically increasing in the inflation rate. This helps contribute to a fundamental property of the model, which is that the equilibrium inflation rate is unique.[7] A high rate of inflation is not an equilibrium because the public rationally understands that with the marginal cost of inflation high, the monetary authority has an incentive to deviate to a lower inflation rate. A low level of inflation is also not an equilibrium because everyone rationally understands

[6] See Ireland (1998) for a test of the hypothesis in a reduced form model.

[7] We adopt the Markov equilibrium concept in our analysis. For an analysis of reputational equilibria in environments like the one we study here, see Chari, Christiano and Eichenbaum (1998) and Ireland (1998).

that with the marginal cost of inflation low, the policymaker has an incentive to deviate up. The model has the implication that, given the state of the exogenous variables of the economy, there is precisely one inflation rate where the marginal costs and benefits of inflation balance so that the policymaker would choose not to deviate. This feature of the model rules out inflation expectations as an exogenous force driving actual inflation. In the language of Chari, Christiano and Eichenbaum (1998), the model rules out 'expectation trap equilibria'. A second feature of the models used in the existing literature is that testing their quantitative implications for inflation is difficult. This is because their reduced form nature implies that the inflation data must be used for calibrating model parameters.

A key advantage of general equilibrium models like the one studied in this paper is that the theory can be tested using a larger set of observations than just inflation and output alone. For example, with general equilibrium models there is the option of calibrating parameters using data other than those on output and inflation, and then using the output and inflation data for testing purposes. In addition, we can use the general equilibrium models to, in effect, rethink the conclusion of the existing literature that there are no expectations traps in inflation. Our second result cited above suggests that expectation traps can occur easily in theory.

We now briefly explain the economic mechanisms in our benchmark model and the intuition underlying our results. In the model, goods are produced in monopolistically competitive markets, so that the level of economic activity is inefficiently low because firms have monopoly power. This inefficiency is what gives the monetary authority the incentive to stimulate the economy by creating a surprise inflation. That it is feasible to stimulate the economy in this way reflects our assumption that a subset of monopolists set their prices before the monetary authority selects the money growth rate. The rest of the prices are set after the monetary authority selects the money growth rate. It is because some prices cannot be changed after the monetary authority's decision, that a monetary expansion can raise output. The fact that output tends to be inefficiently low implies that a rise in output may raise welfare.[8] At the same time, because some prices are set after the monetary authority's decision, unanticipated monetary expansions distort relative prices and, other things the same, reduce welfare. This aspect of the model formalizes an old idea with an extensive literature.[9]

[8] Our model formalizes the idea in Kydland and Prescott (1977) and in Barro and Gordon (1983) that an unanticipated monetary expansion raises output and can raise welfare.

[9] See Cukierman 1983, Parks 1978, and Vining and Elwertowski 1976.

To understand our first result, suppose that the public expects a low inflation, the one associated with the absence of an inflation bias. Then, for a large range of parameter values, it turns out that the price distortions induced by deviating to higher money growth outweigh the associated gains.

The basic finding underlying our second result is that - in contrast with the results in the existing literature - the distortionary costs of unanticipated inflation are always *low* at high rates of inflation in our model. As a result, at high rates of inflation the monetary authority has an incentive to deviate up. Our second result is then not surprising if one supposes (as in the existing literature) that the monetary authority also has an incentive to deviate up at low rates of inflation.

What is it about our benchmark model that causes the marginal cost of unexpected inflation to be low at high inflation? Basically, it is that the elasticity of demand for money with respect to the interest rate is sufficiently large.[10] In this case, at high inflation real money balances are very low and distortions associated with making them even lower are negligible. In later drafts, we plan to illustrate this point by producing a different set of models in which money demand is less elastic and there is a unique equilibrium inflation rate.

The fact that expectation trap equilibria can occur in our benchmark model suggests the possibility that quantitative models like ours may be able to account for the observed prolonged periods of high inflation as well as prolonged periods of low inflation. Whether they do so credibly depends in an important way on the empirical plausibility of their implications for money demand. At an abstract level, it should not be surprising that the behavior of the monetary authority depends in an essential way on the determinants of demand for the object they supply, namely money. But, to our knowledge, this connection has not been made as yet in the literature.

The plan of the paper is as follows. The following section summarizes results in the existing literature. Section 3 presents results based on our benchmark general equilibrium model. Second 4, [yet to be added], describes a different version of our model, in which the money demand elasticity with respect to the interest rate is weaker and the set of equilibria is unique. Section 5 analyzes a model in which the cash-credit good designation is endogenous. We argue that the implications for money demand are better than those of the model in section 3. Still, that model is like the one in

[10] Technically, the condition in the model is that $(R-1)M/P$ goes to zero with high inflation and high R. Here, R denotes the gross rate of interest and M and P denote the money stock and price level. This occurs for all values of the parameters in our model.

section 3 in that it predicts expectation traps and the possibility of a high inflation bias. The final section concludes.

2. The Kydland-Prescott/Barro-Gordon Model

Most of the literature on the inflation bias hypothesis has been conducted in reduced form models. We briefly describe one such model, the KP-BG model to motivate our analysis. The model is static, and the payoff for the monetary authority is given by $a\left[y-x\right]^2 - b\pi^2$, $a, b, x > 0$, where y is a measure of output, $x > 0$ is a measure of 'full employment output' and π is the realized rate of inflation. Output is given by $y = \alpha\left(\pi - \pi^e\right)$, $\alpha > 0$,where π^e is expected inflation. The timing is that private agents choose π^e first and the monetary authority then chooses π. The policymaker's best response, $\pi(\pi^e, x)$ maximizes the monetary authority's payoff given π^e. The model is completed by imposing rational expectations on private agents, namely, $\pi^e = \pi(\pi^e, x)$. The equilibrium inflation rate is given by the solution to this equation, and is denoted by $\pi^*(x)$. Under commitment, the monetary authority chooses π first, and then private agents set $\pi^e = \pi$. The inflation rate implied by this Ramsey-like programming problem is $\pi = 0$. The *inflation bias* is $\pi^*(x)$.

Figure 1 plots the best response function $\pi(\pi^e, x)$ for a fixed x. The equilibrium inflation rate, π^* is the intersection of the best response function with the 45 degree line. The figure shows the two basic results in this literature. First, since the best response function crosses the 45 degree line only once, the equilibrium value of inflation is determined solely by the variable, x, that shift the best response function. If the best response function crossed the 45 degree line more than once, then private sector expectations play an independent role in determining the equilibrium. Chari, Christiano and Eichenbaum (1998) refer to equilibria of this type as 'expectation traps'. The KP-BG model excludes expectation traps. Second, since $a, b, x > 0$ there is always an inflation bias, and it may be substantial.

These two findings hold up in repeated versions of the model as long as attention is restricted to equilibria without reputational mechanisms or trigger strategies. These reputational mechanisms have the unattractive feature that they depend sensitively on the horizon being infinite. In addition, the folk theorem from repeated games implies that the set of equilibria is extremely large and it is difficult to know which of these equilibria are plausible. For these reasons, in our research we focus on stationary Markov equilibria, which rule out such reputational mechanisms.

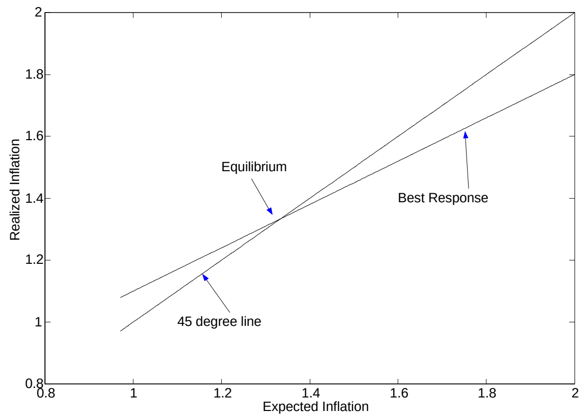

Figure 1: Best Response Function, KP-BG Model

3. The Benchmark Cash-Credit Goods Model

The state of the economy, S, before the monetary policy authority has made its decision, is:

$$S = (\bar{M}, \theta, g),$$

where $\bar{M}$ is the beginning-of-period economy-wide average stock of money. Also, θ, g denote the exogenous shocks, with θ being a shock to technology, and g a shock to government spending. There is a continuum of goods, one for each $j \in (0, 1)$, with each one produced by a given monopolist. In each period a fraction, μ, of these (the 'sticky price firms') sets their prices based on observing S, before the monetary authority has made its decision. We let $p^e(S)$ denote the price set by sticky price firms.

The monetary authority makes its money growth decision, x, conditional on S, $p^e(S)$.[11] We denote its policy action by x. We denote its policy rule by $X(S)$. The state of the economy after the monetary authority makes its decision is:

$$S_1 = (S, x).$$

With these definitions of the economy's state variables, we proceed now to discuss the decisions of firms, households and the monetary authority.

[11] By placing $p^e(S)$ in the monetary authority's policy rule, rather than just p^e, we exclude simultaneous deviations by a positive measure of sticky price firms. A well-known result in game theory is that in checking for sequential rationality, we can ignore histories with simultaneous deviations. For an exposition of this result in macroeconomics, see Chari and Kehoe (1990).

A. Firms

The ω^{th} good, $\omega \in (0,1)$, is produced by a monopolist using the following production technology:

$$y(\omega) = \theta n(\omega),$$

where $y(\omega)$ denotes output, $n(\omega)$ denotes employment, and θ is the technology shock. The price set by the $1-\mu$ firms which set their prices after the monetary authority makes is decision ('flexible price firms') is denoted by $\hat{p}(S_1)$. The prices $p^e(S)$ and $\hat{p}(S_1)$ maximize profits subject to a demand curve discussed below. Because of the constant elasticity form of this demand curve, firms set prices as a fixed markup above marginal cost, the wage rate. For the μ sticky price firms and the $1-\mu$ flexible price firms, this means:

$$(1) \qquad p^e(S) = \frac{w(S_1^e)}{\theta\rho},\ \hat{p}(S_1) = \frac{w(S_1)}{\theta\rho},\ 0 < \rho < 1,$$

where W denotes the nominal wage rate, which is a function of S_1. Here, S_1^e denotes the value of S_1 conditional on the current period monetary authority following the monetary policy rule, i.e.,

$$(2) \qquad S_1^e = (S, p^e, X(S, p^e)).$$

B. Household

The preferences of the representative household are given by

$$\sum_{t=0}^{\infty} \beta^t u(c_t, l_t),\ c_t = \left[\int_0^1 c_t(\omega)^\rho d\omega\right]^{\frac{1}{\rho}},$$

where $c_t(\omega)$ denotes consumption of type ω good and l_t denotes labor time. Goods with $\omega > z$, (where z is a parameter between 0 and 1) are credit goods and goods with $\omega \leq z$ are cash goods. We adopt the following utility function specification:

$$(3) \qquad u(c,l) = \frac{\left[c(1-l)^\psi\right]^{1-\sigma}}{1-\sigma}$$

The sequence of events during the period is as follows. The household begins the period with nominal assets, A. Then it goes to the asset market where it divides A into money holdings, M, and bonds, B, subject to

$$(4) \qquad M + B \leq A,$$

and a cash in advance constraint:

$$(5) \qquad M - [p^e(S)\mu z c_{11} + \hat{p}(S_1)(1-\mu) z c_{12}] \geq 0,$$

where c_{11} and c_{12} denote quantities of cash goods purchased from sticky and flexible price firms, respectively.[12] Nominal assets evolve over time as follows:

$$\begin{aligned}(6) \qquad 0 \;\leq\; & w(S_1)n + (1 - R(S_1))M - z\left[p^e(S)\mu c_{11} + \hat{p}(S_1)(1-\mu)c_{12}\right] \\ & -(1-z)\left[p^e(S)\mu c_{21} + \hat{p}(S_1)(1-\mu)c_{22}\right] + R(S_1)A + \bar{M}(x-1) + D(S_1) - A',\end{aligned}$$

where c_{21} and c_{22} denote the quantities of credit goods purchased from sticky and flexible price goods, respectively. In (6), M denotes the individual household's beginning of period stock of money and $R(S_1)$ denotes the gross nominal rate of return on bonds, and $D(S_1)$ denotes profits after (lump sum) taxes. Finally, B has been substituted out in the asset equation using (4).

Consider the household's asset, goods and labor market decisions. Given that the household expects the monetary authority to choose policy according to X in the future, the household solves the following problem:

$$(7) \qquad v(A, S_1) = \max_{n,M,A',c_{ij};i,j=1,2} u(c,n) + \beta E_{\theta',g',\eta'}[v(A', S', X(S'))|\theta, g]$$

subject to (5), (6), $0 \leq M \leq A$,[13] non-negativity on consumption and labor, and

$$(8) \qquad c = \left[z\mu c_{11}^{\rho} + z(1-\mu)c_{12}^{\rho} + (1-z)\mu c_{21}^{\rho} + (1-z)(1-\mu)c_{22}^{\rho}\right]^{\frac{1}{\rho}}.$$

Also,

$$S' = (\bar{M}x, \theta', g').$$

In (7), v is the household's value function. The solution to (7) yields decision rules of the form $n(A, S_1)$, $M(A, S_1)$, $A'(A, S_1)$, and $c_{ij}(A, S_1)$, $i, j = 1, 2$.

Definition A *Markov equilibrium* is a collection of functions $p^e(S)$, $\hat{p}(S_1)$, $w(S_1)$, $X(S)$, $v(A, S_1)$, $c_{ij}(A, S_1)$, $n(A, S_1)$, $M(A, S_1)$, $A'(A, S_1)$, $R(S_1)$, such that:

[12] We have adopted a slight change in the notation. Concavity of the function that aggregates $c(\omega)$ into c in the utility function implies that $c(\omega)$ is optimally chosen to be constant for ω associated with sticky price cash goods, flexible price cash goods, etc. Thus, we let c_{12} denote $c(\omega)$ for those ω such that $\omega \leq z$ and which are produced by flexible price firms.

[13] What sort of constraint should we place on household debt?

1. The functions v, c_{ij}, n, M, A' solve (7),
2. Firms optimize, i.e., (1) is satisfied,
3. $X(S)$ maximizes $v(\bar{M}, S_1)$ by choice of the third argument of S_1,
4. The asset markets clear, i.e., $A'(\bar{M}, S_1) = \bar{M}x$ and $A = \bar{M} = M(A, S_1)$,
5. The resource constraint is satisfied, i.e., $c_{ij} + g = \theta n_{ij}$, $i, j = 1, 2$,
6. The labor market clears, i.e., $n(A, S_1) = z\left[\mu n_{11} + (1-\mu)n_{12}\right] + (1-z)\left[\mu n_{21} + (1-\mu)n_{22}\right]$,

C. Characterization

In this section we exploit the fact that a Markov equilibrium is the fixed point of a particular mapping. We study the properties of that mapping to determine the uniqueness properties of the equilibrium.

It is convenient to adopt the following scaling of prices and notation:

$$W = \frac{w}{\bar{M}},\ P^e = \frac{p^e}{\bar{M}},\ \hat{P} = \frac{\hat{p}}{\bar{M}},\ q = \frac{\hat{P}}{P^e}.$$

Following is our algorithm for computing a Markov equilibrium. It is best described by considering a particular fixed point problem. For each fixed (θ, g), the fixed point is of the mapping from an expectation of government policy to actual government policy. As a practical matter, it is convenient to characterize policy in terms of q rather than the money growth rate. The government's decision problem maps P^e into q. The government's decision problem is simplified in our setting because its choice of q has no impact on future allocations. As a result, the government faces a static problem. An equilibrium is a P^e such that $q = 1$. We call such a price, $P(\theta, g)$. The mapping from this function to the remaining allocations and prices and to money growth is straightforward.

The mapping can be defined more precisely as follows. For each fixed (θ, g), start with an arbitrary value of P^e and map to q in three steps. First, for arbitrary q, calculate the mapping from (θ, g, P^e, q) to the private allocations and prices that are determined after the monetary authority makes its decision. This allows us to define the policy maker's objective function, $U(\theta, g, P^e, q)$. Second, optimize this objective with respect to q, and denote the solution, $q = q(\theta, g, P^e)$. Finally, adjust P^e until $q = 1$. This value of P^e corresponds to the function, $P(\theta, g)$, referred to in the previous paragraph.

Private Allocations and Prices

We now solve for the private allocations given (θ, g, P^e, q). Let ν and λ denote the multipliers on (5) and (6), respectively.[14] The first order conditions for c_{11}, c_{12}, c_{21}, c_{22}, n, M, A', associated with the Lagrangian representation of (7), are:

$$
\begin{aligned}
u_{11} &= (\lambda+\nu)P^e\mu z \\
u_{12} &= (\lambda+\nu)qP^e(1-\mu)z \\
u_{21} &= \lambda P^e\mu(1-z) \qquad (9)\\
u_{22} &= \lambda P^e q(1-\mu)(1-z), \\
u_n + \lambda\theta\rho P^e q &= 0, \\
\lambda+\nu &= \lambda R, \\
\lambda &= \frac{\beta E_{\theta',g',\eta'}[\lambda' R'|\theta,g,\eta]}{X}.
\end{aligned}
$$

Here, u_{ij} denotes the partial derivative of u with respect to c_{ij}. In the labor Euler equation, we have used the fact, $W = \theta\rho\hat{P}$. Finally, the A' Euler equation uses the fact that $v_1(A,S) = \lambda R$, after applying an envelope result to (26) and (7).

The cash constraint and resource constraint are:

$$
\begin{aligned}
P^e\mu z c_{11} + qP^e(1-\mu)zc_{12} &= 1 \\
g + z\left[\mu c_{11} + (1-\mu)c_{12}\right] + (1-z)\left[\mu c_{21} + (1-\mu)c_{22}\right] &= \theta n \qquad (10)
\end{aligned}
$$

There are 8 unknowns here: c_{ij}, $i,j = 1,2$, n, R, λ and ν. Not counting the last of the household's Euler equations, there are eight equations.[15] These eight equations are used to solve for the 8 unknowns as follows. The equations in (9) imply

$$\frac{u_{11}}{u_{12}} = \frac{u_{21}}{u_{22}} = \frac{\mu}{1-\mu}\frac{1}{q},\ \frac{u_{11}}{u_{21}} = \frac{u_{12}}{u_{22}} = \frac{z}{1-z}R.$$

Making use of (8),

$$c_{12} = c_{11}q^{\frac{-1}{1-\rho}},\ c_{22} = c_{21}q^{\frac{-1}{1-\rho}},\ R = \left(\frac{c_{22}}{c_{12}}\right)^{1-\rho}. \qquad (11)$$

[14] Actually, we scale the multipliers by $\bar{M}$. That is, if $\tilde{\lambda}$ is the multiplier on (6), then $\lambda = \tilde{\lambda}\bar{M}$. This scaling is adopted to assure that λ is not a function of the stock of money.

[15] The last equation will be used to solve for the money growth rate.

The cash in advance constraint can be written as follows:

$$(12) \quad c_{11}\left\{\mu + (1-\mu)q^{\frac{-\rho}{1-\rho}}\right\} = \frac{1}{zP^e}.$$

Combining the n and c_{22} Euler equations, we obtain $u_n + \theta\rho u_{22}/\left[(1-\mu)(1-z)\right]$, or, after making use of (3) and rearranging,

$$(13) \quad \theta(1-n) = \frac{\psi}{\rho}c^{\rho}c_{22}^{1-\rho}.$$

We can now describe an algorithm for finding the 8 unknowns:

- use (12) to compute c_{11} given q, and P^e.
- use (11) to compute c_{12},
- substituting out for n from (10) into (13), we obtain an expression involving c_{ij}, $i,j = 1,2$ alone. Given c_{11}, c_{12} and the relationship in (11), (13) is converted into a nonlinear equation in the single unknown, c_{21}. We can solve this for c_{12}, which then gives c_{22} using (11),
- R is obtained from (11),
- n is obtained from (10),
- the multipliers are obtained from $\lambda = u_{21}/\left[P^e\mu(1-z)\right]$ and $\nu = \lambda(R-1)$.

Denote the eight functions found by this algorithm,

$$(14) \quad \begin{aligned} c_{ij}(P^e,q,\theta,g),\ i,j &= 1,2,\ R(P^e,q,\theta,g),\ n(P^e,q,\theta,g), \\ &\quad \lambda(P^e,q,\theta,g),\ \nu(P^e,q,\theta,g) \end{aligned}$$

Government Problem

We can summarize the previous discussion as providing functions:

$$c = c(P^e,q,\theta,g),\ n = n(P^e,q,\theta,g),$$

where c is obtained by substituting (14) into (8). The first two functions can be substituted into the utility function,

$$\begin{aligned} & U(P^e,q,\theta,g) \\ = \ & u\left[c\left(P^e,q,\theta,g\right), n\left(P^e,q,\theta,g\right)\right]. \end{aligned}$$

We assume that U is concave in q. The findings in our computational experiments were consistent with this assumption. Define

$$q(\theta, g, P^e) = \arg\max_q U(P^e, q, \theta, g),$$

subject to the condition that the nominal rate of interest is non-negative, i.e., $c_{21}(P^e, q, \theta, g) \geq c_{11}(P^e, q, \theta, g)$.

The function, $q(\theta, g, P^e)$, is the monetary authority's best response, given θ, g, P^e. Let $L'(q)$ denote the derivative of the monetary authority's return with respect to $m:$

$$(15) \quad L'(q) = L_1'(q) + \lambda \left[c_{21,q}(P^e, q, \theta, g) - c_{11,q}(P^e, q, \theta, g)\right],$$

where

$$(16) \quad L_1'(q) = u_c c_q \left(P^e, q, \theta, g\right) + u_n n_q \left(P^e, q, \theta, g\right),$$

and λ is the Lagrange multiplier. A necessary and sufficient condition for an optimum is $L'(q) = 0$. We show below that when the constraint is binding, i.e., $c_{21} = c_{11}$, then $c_{21,q} \geq c_{11,q}$. It follows that, at the optimum where the constraint is not binding, $L_1'(q) = 0$. At an optimum where it is binding, $L_1'(q) \leq 0$. To help interpret (16), it is useful to add and subtract $u_c\theta(c/c_2)^{(1-\rho)}n_q$, to obtain:

$$(17) \quad L_1'(q) = u_c c_q - \theta u_c (\frac{c}{c_2})^{1-\rho} n_q + \left[u_n + \theta u_c (\frac{c}{c_2})^{1-\rho}\right] n_q.$$

We now develop formulas for c_q and n_q. We are interested in evaluating these derivatives at an equilibrium, i.e., $q = 1$. Consider first c_q. Differentiating (8),

$$(18) \quad c_q = \left(\frac{c}{c_1}\right)^{1-\rho} z \left[\mu c_{11,q} + (1-\mu)c_{12,q}\right] + \left(\frac{c}{c_2}\right)^{1-\rho} (1-z) \left[\mu c_{21,q} + (1-\mu)c_{22,q}\right],$$

where $c_{ij,q}$ is the derivative of c_{ij} with respect to q, evaluated at $q = 1$. From the resource constraint, we obtain:

$$(19) \quad n_q = \frac{z\left[\mu c_{11,q} + (1-\mu)c_{12,q}\right] + (1-z)\left[\mu c_{21,q} + (1-\mu)c_{22,q}\right]}{\theta}.$$

Substituting for c_q and n_q in (17) we obtain

$$(20) \quad L_1' = u_c \left[\left(\frac{c}{c_1}\right)^{1-\rho} - \left(\frac{c}{c_2}\right)^{1-\rho}\right] z \left[\mu c_{11,q} + (1-\mu)c_{12,q}\right] + \left[u_n + \theta u_c (\frac{c}{c_2})^{1-\rho}\right] n_q,$$

where L_1' denotes $L_1'(q)$ at $q = 1$. Using (11), we obtain

$$(21) \quad L_1' = u_c \left(\frac{c}{c_2}\right)^{1-\rho} (R-1)\, z \left[\mu c_{11,q} + (1-\mu)c_{12,q}\right] + \left[u_n + \theta u_c (\frac{c}{c_2})^{1-\rho}\right] n_q.$$

From (12) and the first equation in (11),

$$c_{11,q} = c_1 \frac{(1-\mu)\rho}{1-\rho}, \; c_{12,q} = -c_1 \frac{1-(1-\mu)\rho}{1-\rho}, \tag{22}$$

so that

$$\mu c_{11,q} + (1-\mu) c_{12,q} = -c_1(1-\mu). \tag{23}$$

Substituting this into (21):

$$L_1' = -u_c \left(\frac{c}{c_2}\right)^{1-\rho} (R-1)\, z c_1 (1-\mu) + \left[u_n + \theta u_c (\frac{c}{c_2})^{1-\rho}\right] n_q. \tag{24}$$

Notice that if the government could commit itself to monetary policy, it would follow the Friedman rule and set $R = 1$, so that the first term would be zero. In light of this, we call this term the inflation distortion. We call the second term the monopoly distortion because, if firms behaved competitively, the marginal rate of substitution between credit good consumption and leisure would be set equal to the corresponding marginal rate of transformation, so the second term would be zero.

We now use (24) to establish that there are at least two equilibria. Let

$$\psi_{ID}\left(\frac{c_1}{c_2}\right) = \left[\left(\frac{c_1}{c_2}\right)^{\rho-1} - 1\right] z \frac{c_1}{c_2}(1-\mu).$$

Then, it is easy to see that

$$-u_c \left(\frac{c}{c_2}\right)^{1-\rho} c_2 \psi_{ID}\left(\frac{c_1}{c_2}\right)$$

is the inflation distortion. In the appendix we show that n_q is of the form $\psi_{MD}(c_1/c_2)c_2/(\theta(1-\rho))$. Since $u_n + \rho\theta u_c (c/c_2)^{1-\rho} = 0$ from the labor Euler equation, it follows that (24) can be rewritten as

$$L_1' = u_c \left(\frac{c}{c_2}\right)^{1-\rho} c_2 \left[-\psi_{ID}\left(\frac{c_1}{c_2}\right) + \psi_{MD}\left(\frac{c_1}{c_2}\right)\right] \tag{25}$$

Consider the inflation distortion function, ψ_{ID}. It is straightforward to show that

$$\psi_{ID}(0) = \psi_{ID}(1) = 0.$$

In the appendix, we show that $\psi_{MD}(0) > 0$. Suppose next that $\psi_{MD}(1) \leq 0$. Then, $L_1' \leq 0$ at the allocations associated with the Ramsey rule.[16] It follows that the Ramsey rule and the associated

[16] The Ramsey rule corresponds to an equilibrium for the private economy in which $R = 1$, so that $c_1 = c_2$.

allocations are a Markov equilibrium. Since ψ_{ID} and ψ_{MD} are continuous functions, if $\psi_{MD}(1) < 0$, it follows that there exists some value of c_1 and c_2 such that $-\psi_{ID}(c_1/c_2) + \psi_{MD}(c_1/c_2) = 0$. These allocations and the policies associated with these allocations constitute another Markov equilibrium. Suppose next that $\psi_{MD}(1) > 0$. Then, since $\psi_{MD}(0) > 0$, by continuity it follows that if there are any allocations at which $L_1' = 0$, there are at least two. We have established:

Proposition 1: Generically, (i.e., with the exception of cases when $\psi_{MD}(1) = 0$) there are at least two Markov equilibria.

[A numerical example will be provided.]

4. Alternative Cash-Credit Goods Models

[to be added]

5. Endogenous Cash-Credit Goods Model

Section 3displayed a cash-credit good model in which expectation traps and a high inflation bias are possible. This model has an important deficiency, however, in that it does not reproduce the dynamics of observed money demand. We propose a framework which offers some hope of resolving these difficulties. Because the framework gives households greater flexibility in their cash decisions, it is perhaps not surprising that it also implies the existence of expectation trap equilibria and a potentially high inflation bias.

We extend the model with differentiated goods studied in the previous section. The novelty here is that households can choose whether to purchase each good with cash or with credit. Cash purchases are costly because households forego interest, while credit purchases require payment of a fixed cost which differs depending on the type of good. For the sake of tractability, we assume that this fixed cost is zero for a subset of the goods and is the same and positive for the rest. We refer to this model as the endogenous cash-credit good model and the previous model as the exogenous cash-credit good model. In spirit, our endogenous cash credit good model is similar to the financial intermediation models of Aiyagari, Braun and Eckstein (1998), Cole and Stockman (1992), Freeman and Kydland (1994), Ireland (1994), Lacker and Schreft (1996), Schreft (1992) and others. All of these emphasize the tension between the use of costly transactions technologies and the interest cost of using money to finance transactions. These models and ours have the feature that at low levels of expected inflation, households use cash in a relatively large number of transactions, while at high levels little cash is used. In our preliminary research we assume that in each period the household chooses whether to use cash or credit for a given good before that period's monetary policy decision is made.

A. Firms

As in section 3.we assume that intermediate good firms sell output directly to households, who then aggregate individual consumption goods using a CES aggregator function. A fraction, μ, of these firms, called sticky price firms, set prices before the monetary authority's policy is chosen, and the rest, the flexible price firms, set their prices afterward. Utility maximization by households leads to the usual constant elasticity demand functions. The firms have the same production functions as the intermediate good firms in section 3.Profit maximization leads to the usual condition that they set price to a constant markup over marginal cost, which is the wage rate. Let $p^e(\bar{M})$ denote the pricing rule of the sticky price firms.

B. Households

The preferences of the representative household are given by: $\sum_{t=0}^{\infty} \beta^t u(c_t, l_t)$, $c_t = \left[\int_0^1 c_t(j)^\rho dj\right]^{\frac{1}{\rho}}$, where $c_t(j)$ denotes consumption of type j good and l_t denotes labor time. Households choose whether a given consumption good, $c_t(j)$, $j \in (0,1)$, is a cash good or a credit good. For goods with $j > \bar{z}$, (where $\bar{z}$ is a parameter between 0 and 1), the fixed cost of purchasing with credit is zero, and we assume these goods are always purchased with credit. To purchase each good with $j \leq \bar{z}$ using credit, a fixed cost in terms of time, η, must be paid. Without loss of generality, we suppose that the household selects a parameter, $z \in (0, \bar{z})$, such that goods with an index greater than z are purchased on credit and goods with an index less than z are purchased with cash. For a given value of z, the household's labor time, including time spent working in the market, n, is $l = n + (\bar{z} - z)\,\eta$.

The sequence of events during the period is as follows. The household begins the period with nominal assets, A. It then selects a value for z. It then goes to the asset market where it divides A into money holdings, M, and bonds, B subject to (4). Its cash in advance constraint is (5).

As before, S is the state of the economy after the monetary authority has made its choice, i.e., $S = (\bar{M}, p^e(\bar{M}), Z, G)$, where Z denotes the economy-wide average value of z. The asset accumulation equation is the analog of (6).

Consider the household's consumption and employment decisions for a given value of z. These decisions solve the following problem:

$$w(A, z, S) = \max_{c,n,A'} u(c, n + (\bar{z} - z)\,\eta) + \beta v(A, \bar{M}G),$$

subject to (5) and the analog of (4). Here, v is the household's value function at the beginning of the next period, before it chooses next period's z. Solving this problem yields decision rules of the form $c(z, A, S)$, $n(z, A, S)$ and $A'(z, A, S)$. The choice of z solves the following dynamic programming problem:

$$(26) \quad v(A, \bar{M}) = \max_{z} w(A, z, S^e),$$

where S^e is the state of the economy if the monetary authority follows its money growth rule, i.e., $S^e = (\bar{M}, p^e(\bar{M}), Z(\bar{M}), \Gamma(\bar{M}, p^e(\bar{M}), Z(\bar{M}))$, where $Z(\bar{M})$ denotes the economy-wide average value of z associated with an initial money stock of $\bar{M}$. The solution to (26) yields a decision rule of the form $z(A, \bar{M})$.

The monetary authority's policy function, $\Gamma(\bar{M}, p^e(\bar{M}), Z(\bar{M}))$, maximizes $w(\bar{M}, z, S)$ by choice of the third element of S. With one additional condition, $z(\bar{M}, \bar{M}) = Z(\bar{M})$, a stationary Markov equilibrium is defined analogously to that in the exogenous cash-credit goods model.

C. Results

For a range of parameter values it turns out that there are two Markov equilibria in the endogenous cash-credit good model: one with a low inflation bias and the other with a high inflation bias. To develop intuition for this result, in Figure 2, we plot the best response of the monetary authority in terms of its optimal growth rate of the money supply, G, against the corresponding expected growth rate, g.[17] The points labelled A and C correspond to the two Markov equilibria. Over the range A to B the model behaves in exactly the same way as the exogenous cash-credit goods model. When g rises above the point corresponding to B, households find it optimal to pay the fixed costs and purchase an increasing fraction of goods using credit. As a result, the marginal cost of unexpected inflation - the implicit tax on cash goods - is actually falling as expected money growth rises, since households react to higher expected money growth by reducing the fraction of goods purchased with cash. This explains why the best response function has a steeper slope after the point B, and why it intersects the 45 degree line at point C. This multiplicity of equilibria

[17]The underlying parameter values are $\beta = 1/1.03$, $\eta = .065$, $\psi = 1.64$, $\rho = .83$, $\mu = 0.1$, $\bar{z} = 0.3$, $\sigma = 1.01$.

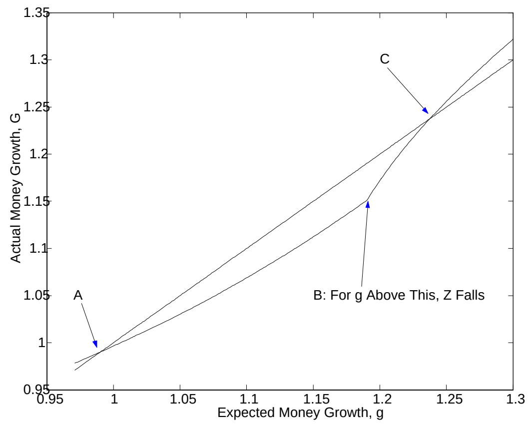

Figure 2: Monetary Authority's Best Response

implies that it is possible for the economy to get caught in an expectations trap. In such a trap, if private agents, for whatever reason, expect the high money growth associated with point C, they choose to purchase a small fraction of goods with cash and set prices at a high level. The monetary authority optimally chooses to validate these expectations for two reasons. First, the small number goods purchased with cash implies that the cost - in terms of the implicit tax on cash goods - of high money growth is small. Second, the fact that agents have posted high prices means that if the monetary authority does not validate expectations, output will be inefficiently low. The existence of multiple, stationary Markov equilibria also raises the possibility that the economy could be subject to excessive volatility. We conjecture that, in this economy, there are 'sunspot' equilibria in which inflation rates and output fluctuate erratically over time. For example, suppose that at the beginning of each period, agents observe a random variable which can take on two values, h, l, and is very persistent over time. In this case, we conjecture that inflation rates will fluctuate around A for a long period of time, occasionally change by a large amount and then fluctuate around C for a long period of time.

D. Money Demand and Extensions

The money demand relationship in this model is:

$$\frac{c}{M/P} = 1 + \left[\frac{1-z}{z}R\right]^{\frac{1}{1-\rho}},$$

where c is total consumption, $c = zc_1 + (1-z)c_2$, and c_1 and c_2 denote consumption of each cash and credit good, respectively. We believe that this money demand function represents an improvement over the one in the exogenous cash credit good model, and studied empirically in Lucas and Stock and Watson. For example, it is likely to be consistent with the well known observation that short run money demand elasticities are smaller than long run money demand elasticities. That is, the immediate impact on real balances of a change in the interest rate is smaller than the longer run impact. To see why, consider a stochastic version of our model in which money shocks cause interest rates to be positively serially correlated. Since the current interest rate is not known at the time that z chosen, then the immediate response of velocity is exactly the same as in the cash credit good model. Dynamically, however, the response to velocity is likely to be stronger, as z falls in response to the rise in R.

Another feature of empirical money demand equations is that shocks tend to be persistent and heteroscedastic. This is likely to be a feature of our model, since money demand shocks are functions of the product of z and R. Finally, an interesting capital-theoretic extension is one in which z in the current period is determined by its past value and by incurring current costs. In such an extension velocity may exhibit a trend, and the data suggests that some empirical measures do too.

We plan to consider stochastic versions of this model. Since the nonstochastic version has two equilibria, it seems likely that in the stochastic version monetary policy will exhibit regime shifts. Clarida, Gali and Gertler (1999) and Taylor (1999) argue that the data seems to show regime shifts. We plan to investigate whether these resemble the regime shifts in the model.

6. Conclusion

The results in this paper show that absence of commitment in monetary policy is in principle capable of rationalizing a high inflation bias, as well as prolonged periods of low and high inflation. The analysis suggests that whether it can do so depends on how high is the elasticity of money demand with respect to the interest rate.

An analysis of an extended version of our benchmark model, reported in section 5convinces us that there is a good chance that it is indeed high enough. In the extended version of the model we endogenized the cash-credit good designation of a given good. Basically, any good can be treated as a cash good, but the payment of a fixed cost makes it possible to treat it as a credit good instead. This model gives people even more opportunities to substitute out of money (cash goods) than the model emphasized in the text, and so - in view of the intuition developed here - it is not surprising that that model also has multiple equilibria.

The particular empirical virtue of this model is that it holds the potential to account quantitatively for a variety of puzzles noted in the empirical literature on money demand. Specifically, the data suggest that short run interest elasticities of money demand are lower than longer run elasticities, that shocks to money demand are persistent, and that there have been secular shifts in velocity. Standard monetary models like the one emphasized in this draft of the paper cannot reproduce these features of the data, even qualitatively. The endogenous cash credit good model can do so qualitatively and seems promising quantitatively. We plan to explore this further.

A convincing test of the inflation bias hypothesis requires showing that our results are robust to various extension of our models. As we noted in the introduction, the credibility of the model's implications for inflation depend on how well it does in accounting for the dynamics of a broader set of macroeconomic variables. We intend to extend the type of model described here to allow for capital accumulation, shocks to technology, government consumption, financial intermediation and the like. Furthermore, we plan to study other types of sticky price models, such as those of Calvo (1983), Chari, Kehoe and McGrattan (1998), Taylor (1999), Gust (1998), Caplin and Spulber (1987), Erceg, Henderson and Levin (1999), King and Wolman (1996), Rotemberg (1996), Rotemberg and Woodford (1999) and others.

In addition, in this paper we have abstracted from government debt and taxes. We plan to incorporate these into our analysis because they change the incentives to generate unexpected inflation and so are likely to have an impact on any assessment of the inflation bias hypothesis.

Finally, a feature of the models considered here is that the ability of the monetary authority to affect output is not substantially different at high and low inflations. If firms could do something to make their prices more flexible at high inflation, then our multiple equilibrium result may possibly go away. This is something that needs to be investigated.

Appendix

A1. Appendix

In this appendix we prove two results used in the text. First, we show that n_q is of the form:

$$n_q = \frac{c_2 \psi_{MD}\left(\frac{c_1}{c_2}\right)}{(1-\rho)\theta},$$

and that $\psi_{MD}(0) > 0$. Second, we show that when the non-negativity constraint on the nominal interest rate is binding, then $c_{21,q} \geq c_{11,q}$.

To establish the first result, we begin by differentiating the resource constraint to get:

$$\text{(A1)} \quad n_q = \frac{z\left[\mu c_{11,q} + (1-\mu)c_{12,q}\right] + (1-z)\left[\mu c_{21,q} + (1-\mu)c_{22,q}\right]}{\theta}.$$

From (11),

$$\text{(A2)} \quad c_{22,q} = c_{21,q} - \frac{c_2}{1-\rho},$$

and using (23), we obtain:

$$\text{(A3)} \quad \psi_{MD}\left(\frac{c_1}{c_2}\right) \equiv \frac{(1-\rho)\theta}{c_2} n_q = (1-\rho)\left\{-\frac{c_1}{c_2} z(1-\mu) + (1-z)\left[\frac{c_{21,q}}{c_2} - \frac{1-\mu}{1-\rho}\right]\right\}$$

To get $c_{21,q}$ we work with (13), after substituting out for θn from (10) and for c using (8) and for c_{12} and c_{22} from (11) to obtain:

$$\begin{aligned} \theta &= g + \left[z c_{11} + (1-z) c_{21}\right]\left[\mu + (1-\mu) q^{\frac{-1}{1-\rho}}\right] \\ &\quad + \frac{\psi}{\rho}\left[z c_{11}^{\rho} + (1-z) c_{21}^{\rho}\right]\left[\mu + (1-\mu) q^{\frac{-\rho}{1-\rho}}\right] c_{21}^{1-\rho} \frac{1}{q}. \end{aligned}$$

Totally differentiating this expression, we find:

$$\text{(A4)} \quad c_{21,q} = \frac{-c_{11,q} z\left[1 + \psi\left(\frac{c_2}{c_1}\right)^{1-\rho}\right] + \left[z c_1 + (1-z) c_2\right]\frac{1-\mu}{1-\rho} + \frac{\psi}{\rho} c^{\rho} c_2^{1-\rho} \frac{1-\rho\mu}{1-\rho}}{(1-z)(1+\psi) + \frac{\psi}{\rho}(1-\rho)\left(\frac{c}{c_2}\right)^{\rho}}$$

Using the formula for $c_{11,q}$ in the text, this reduces to:

$$\text{(A5)} \quad \frac{c_{21,q}}{c_2} = \frac{-\frac{c_1}{c_2}\frac{(1-\mu)\rho}{1-\rho} z\left[1 + \psi\left(\frac{c_1}{c_2}\right)^{\rho-1}\right] + \left[z\frac{c_1}{c_2} + 1 - z\right]\frac{1-\mu}{1-\rho} + \frac{\psi}{\rho}\left(\frac{c}{c_2}\right)^{\rho}\frac{1-\rho\mu}{1-\rho}}{(1-z)(1+\psi) + \frac{\psi}{\rho}(1-\rho)\left(\frac{c}{c_2}\right)^{\rho}}.$$

Substituting (A5) into (A3) it is easily verified that ψ_{MD} is a continuous function of c_1/c_2.

To verify $\psi_{MD}(0) > 0$, it is sufficient to establish that the expression in square brackets in (A3) is positive when $c_1/c_2 = 0$. Evaluating this, taking into account (A5):

$$\begin{aligned}
\frac{c_{21,q}}{c_2} - \frac{1-\mu}{1-\rho} &= \frac{(1-z)\frac{1-\mu}{1-\rho} + \frac{\psi}{\rho}(1-z)\frac{1-\rho\mu}{1-\rho}}{(1-z)(1+\psi) + \frac{\psi}{\rho}(1-\rho)(1-z)} - \frac{1-\mu}{1-\rho} \\
&= \frac{1}{1-\rho}\frac{1-\mu+\frac{\psi}{\rho}(1-\rho\mu)}{1+\psi+\frac{\psi}{\rho}(1-\rho)} - \frac{1-\mu}{1-\rho} \\
&= \frac{1}{1-\rho}\left\{\frac{1-\mu+\frac{\psi}{\rho}(1-\rho\mu) - (1-\mu)(1+\psi) - (1-\mu)\frac{\psi}{\rho}(1-\rho)}{1+\psi+\frac{\psi}{\rho}(1-\rho)}\right\} \\
&= \frac{1}{1-\rho}\frac{\psi}{\rho}\frac{(1-\rho)\mu}{1+\psi+\frac{\psi}{\rho}(1-\rho)} > 0.
\end{aligned}$$

This establishes the desired result.

We now establish our second result, namely, that $c_{21,q} \geq c_{11,q}$ when $c_{21} = c_{11} = c_{22} = c_{12} = c$. Substituting for $c_{21,q}$ from (A4), we need to show that

$$\frac{-c_{11,q}z\,[1+\psi] + c\frac{1-\mu}{1-\rho} + \frac{\psi}{\rho}c\frac{1-\rho\mu}{1-\rho}}{(1-z)(1+\psi) + \frac{\psi}{\rho}(1-\rho)} \geq c_{11,q},$$

or

$$\left\{\frac{1-\mu}{1-\rho} + \frac{\psi}{\rho}\frac{1-\rho\mu}{1-\rho}\right\} \geq \frac{c_{11,q}}{c}\left\{z(1+\psi) + (1-z)(1+\psi) + \frac{\psi}{\rho}(1-\rho)\right\},$$

or, substituting for $c_{11,q}$ and simplifying,

$$\left\{\frac{1-\mu}{1-\rho} + \frac{\psi}{\rho}\frac{1-\rho\mu}{1-\rho}\right\} \geq \frac{(1-\mu)\,\rho}{1-\rho}\left\{(1+\psi) + \frac{\psi}{\rho}(1-\rho)\right\}$$

or,

$$1-\mu+\frac{\psi}{\rho}\,(1-\rho\mu) \geq (1-\mu)\,\rho(1+\psi) + (1-\mu)\,\psi(1-\rho).$$

Dividing through by $1-\mu$, we need to show that

$$1+\frac{\psi}{\rho}\frac{1-\rho\mu}{1-\mu} \geq \rho(1+\psi) + \psi(1-\rho)$$

or

$$1+\frac{\psi}{\rho}\frac{1-\rho\mu}{1-\mu} \geq \rho+\psi.$$

Since $\rho \leq 1$ and $(1-\rho\mu)\,/\,[\rho(1-\mu)] = (1/\rho-\mu)\,/(1-\mu) \geq 1$, we have the desired result.

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