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Abstract

Recent monetary history has been characterized by monetary authorities which have been, alternatively hard and soft on inflation. In a vintage capital framework, investment decisions are not easily reversed. Therefore, expectations of policy as well as current policy are important to the investment decision. Here, a vintage capital model is used to assess the value of central bank credibility for a policy change. Policy in this model is assumed to be private information of the central banker. Agents learn about that policy which to study the ensuing transitional dynamics following a change in monetary policy regime.

1. Introduction

The motivation for this study is threefold. The first of these is that many central banks appear to alternate between distinct policy regimes associated with higher and lower rates of monetary expansion. This is possibly a reflection of the central bank's attitudes towards inflation. The early eighties seem to be characterized by much higher monetary growth rates - annualized rates of 6% to 8% - in the U.S., in contrast to the middle to late nineties where money growth rates fell to around a 2% annualized rate. A possible explanation is that money growth rates reflect the values of the central bank. A low money growth regime places a higher value on low inflation while a high money growth regime places a relatively lower value on inflation.

Secondly, although inflationary expectations are difficult to measure, there is a belief that inflationary expectations display a significant amount of "sluggishness" in the sense that they have a low contemporaneous correlation with current money growth (Thiessan, 1996). This can be seen to the extent that nominal interest rates reflect expectations of inflation. Changes in nominal interest rates tend to lag changes in money growth. For example, Andolfatto and Gomme (1997) show evidence of "sticky expectations" by looking at monetary policy and interest

rates in Canada from 1955 to 1995. In particular, they note that it took a significant amount of time for nominal interest rates to rise during the "loose money" regime of the 1970's and to fall during the "loose money" regime of the 1980's. A potential explanation for this behavior is that consumers observe the current monetary authority and base their expectations of future money growth and inflation on the past actions of that regime. Therefore, if a previously "loose" central bank tries to take a hard stance against inflation, it takes a while to establish credibility with consumers.

Finally, many economists agree that the empirical evidence supports the view that unexpected increases in the growth of the money supply increase output and employment and decrease nominal interest rates¹. The reasoning behind this view is that unexpected increases in money growth create two opposing effects. The first of these is referred to as a *liquidity effect*: Unanticipated monetary expansions create excess supply of loanable funds thus driving down the real interest rate. The second effect assumes people believe that higher current money growth will be followed by higher future money growth. This results in expectations of higher future prices and causes borrowers and lenders to add an inflation premium to

¹For a discussion of the empirical evidence, see the work by Friedman and Schwartz (1963), Barro (1978), Barro and Rush (1980), King (1990)

nominal interest rates. This *anticipated inflation effect* raises nominal interest rates and depresses economic activity. The evidence supports the view that, at least in the short run, the liquidity effect of a money shock dominates the anticipated inflation effect.

The monetary transmission mechanism used here is a limited participation model, as used by such authors as Lucas (1990), Fuerst (1990), and Christiano and Eichenbaum (1992) to generate the liquidity effect of a money shock. Limited participation models assume that financial institutions are in continuous contact with firms who borrow to finance either investment or labor expenditures. Households save through deposits held by the financial intermediary, but cannot continuously adjust their savings decision. The central bank conducts open market operations directly with these financial institutions. In this framework, unexpected monetary injections create "excess liquidity" in the financial market. Consequentially, firms are forced to absorb a disproportionately large share of the added money which puts downward pressure on real interest rates and increases economic activity. The two new features are the nature of capital accumulation and the formation of expectations.

Evidence from plant level data show that capital accumulation doesn't occur smoothly and continuously, as standard neoclassical models imply. Instead, cap-

ital accumulation is "lumpy", occurring all at once when old plants are replaced with new ones. Doms and Dunne (1993) use a 12,000 plant study and find that, over a 15 year period, 25% of a plant's investment expenditures is concentrated in a single year - 50% is concentrated in a contiguous 3 year period. This suggests that a vintage capital model might be a more realistic view of capital accumulation. Some of the earliest work on vintage capital was pioneered by Robert Solow. In Solow (1962), capital had a fixed lifetime and the amount of labor in a plant was fixed over its lifetime. Here, I employ a simplified version of Cooley, Greenwood, and Yorukoglu (1997). In this setup, the firm is able to efficiently allocate labor over firms. A result of this is that older firms will employ less labor than firms with newer technology. This is consistent with the observation that older firms are smaller than newer firms.

For simplicity, it is assumed that there are only two regimes available to the monetary authority. Changes between regimes will be purely exogenous. That is, strategic interactions that might occur between the central bank and the general public are ignored here. Expectations here will reflect slowly evolving beliefs on money growth held by the public. Rather than perfect information environments where policy announcements are taken to be perfectly credible, here the credibility of the monetary authority is determined by past behavior. Consumers

make inferences as to the credibility of the policy announcement and gradually update that belief through observations of money growth. Consequently, inflation forecasts and hence nominal interest rates take time to adjust to regime switches, thus exacerbating the effects of disinflation policy.

Several previous studies have looked at the relationships between monetary policy, credibility, and beliefs. Backus and Driffill (1985a) look at the policy game model of Barro and Gordon (1883). Central bankers are considered to be either "wet" or "hard-nosed". The public forms beliefs as to the true identity of the central banker and updates those beliefs in a Bayesian fashion. They do not, however, consider regime shifts. Cukierman and Meltzer (1986) look at a central bank with time dependant preferences over inflation and output. The public can't observe the preferences of the central bank, but make inferences by observing money growth. Laxton, Ricketts, and Rose (1994) examine the relationship between regime shifts and imperfect credibility. They look at a model that features expectations formed with a combination of backward-looking, least squares learning, and Bayesian updating of beliefs about central bank credibility. Their framework reveals relatively long periods of systematic errors in expectations, especially when there are regime changes.

The remainder of the paper is as follows: In section two, the economic environ-

ment is outlined. The highlight of this section is the firm's investment decision. In standard models, the firm's investment decision can be reversed in the next period. Therefore, the first order condition for capital accumulation only involves a one period forecast of the state of the world. Here, investment decisions are irreversible for the lifetime of the capital. Therefore, the forecast must be made over the lifetime of capital. In section three, the model's general equilibrium is explicitly defined. Sections four and five describe the model's balanced growth path and detrend the model to render it stationary. In section six, the model is calibrated to match salient features of the US. economy. Sections seven and eight analyze the results of the model by exploring the impact of monetary shocks on the model's steady state and the transitional dynamics. The final section offers some concluding remarks and directions for future research.

2. The Economic Environment

There exists a representative firm which operates a continuum of manufacturing plants distributed over the unit interval. Plants are indexed by the age of the capital. Capital has a lifetime of N periods after which it is scrapped. Therefore, every period an age N plant is retired and must be replaced with a new plant. The firm must decide how to allocate labor across plants as well as how much

capital to install in a new plant. Once the capital is installed, it is in place until it is retired in N periods. Capital goods become more productive over time, so as a plant ages its capital becomes less productive relative to new capital. There is no physical depreciation. Agents in the economy allocate time over labor and leisure and income over cash and deposits. There is a financial intermediary that holds deposits for consumers and loans money to the firm. The role of government is to adjust the money supply via open market operations conducted directly with the financial intermediary.

2.1. Beliefs

For simplicity, assume that there are only two choices for money growth. Let the policy variable for money growth be $\tilde{\mu}_t$ where $\tilde{\mu}_t \in \{\mu_H, \mu_L\}$ where $\mu_H \succ \mu_L$. Therefore, μ_H can be considered a "soft money" regime and μ_L a "hard money" regime. Monetary regimes switch back and forth between regimes according to the following Markov process.

$$\phi_{ij} = \Pr \left\{ \mu_t = \mu_j / \mu_{t-1} = \mu_i \right\} ; i, j = L, H \quad (2.1)$$

Let μ_t denote the realized rate of money growth at time t . Money supply grows exogenously according to the following process.

$$\widehat{\mu}_t = \mu_t + \varepsilon_t \quad (2.2)$$

where ε is a random disturbance drawn from the normal distribution.

$$f_i(\varepsilon) = \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left\{\frac{-\varepsilon^2}{2\sigma_i^2}\right\} ; i = L, H \quad (2.3)$$

Individuals in this economy can't observe the true policy regime, $\tilde{\mu}$, that they are currently in, but they can observe actual money growth and make inferences about the current regime. Given the exogenous nature of money supply, the only information that would be use for inferring regime type will be based on the known parameters and on observation of the history of money growth.

Assume that individuals share a common initial prior for the probability that the current regime is a hard money regime.

$$b_0 = \Pr\{\tilde{\mu} = \mu_L\} \quad (2.4)$$

Let the time t belief on the current regime, conditional on past money growth be

$$b_t = \Pr \left\{ \widetilde{\mu}_t = \mu_L / \mu_t, \mu_{t-1}, \dots \right\} \quad (2.5)$$

the probability that the current regime is a hard money regime, conditional on the money growth history and the initial belief, b_0 . The individual enters period t with belief b_t , observes time t money growth, and then updates his beliefs according to Bayes rule.

$$b_{t+1} = \frac{g_L(b_t, \mu_t, \mu_{t-1})}{g_L(b_t, \mu_t, \mu_{t-1}) + g_H(b_t, \mu_t, \mu_{t-1})} \quad (2.6)$$

where

$$\begin{aligned} g_L(b_t, \mu_t, \mu_{t-1}) &= [b_t \varphi_{LL} + (1 - b_t) \varphi_{HL}] f(\mu_t - (1 - \psi) \mu_L - \psi \mu_{t-1}) \\ g_H(b_t, \mu_t, \mu_{t-1}) &= [b_t \varphi_{LH} + (1 - b_t) \varphi_{HH}] f(\mu_t - (1 - \psi) \mu_H - \psi \mu_{t-1}) \end{aligned} \quad (2.7)$$

Note that g_L and g_H involve two terms. The first is the probability that the individual attaches to currently being in a low or high money growth regime respectively. The second term represents the probability of observing the current money growth given the belief of regime.

It should be noted that learning will occur in this economy. Suppose that an agent believes that the current regime is that of tight money (b is close to one). If the true money regime is that of loose money, Bayesian updating implies that the agent's value of b will fall over time. For a long enough time period with the money authority maintaining a loose money regime, the agents belief will eventually fall to zero. The only exception to learning is if the agents initial prior is exactly 1 or exactly zero.

Also, note that with incomplete information, the central banker has the ability to fool the agents repeatedly. An agent could have the belief that a central banker is a loose when he is actually tight. If the banker continually switches policy, he can fool the agent indefinitely and complete learning will never occur.

2.2. The Representative Firm's Problem

There exists firm that owns a continuum of manufacturing plants distributed over the unit interval. A particular plant is identified by the age of the capital employed. Let ψ_i denote the measure of age i plants. Capital has a life of N years, after which it is unusable and, hence, has a value of zero. With a uniform age distribution, $\psi_i = 1/N$. Therefore, every period, an age N plant is scrapped and replaced by a new plant. The firm manager must decide the size of a new

plant as well as how to allocate labor over the various plants. Consider an age i plant. It has at its disposal k_i efficiency units of capital and employs l_i units of labor. It produces output according to the following technology

$$y_i = k_i^\alpha l_i^\omega \quad \alpha + \omega \leq 1 \quad (2.8)$$

As in Greenwood, et al (1994), investment specific technological change is formalized by the ability to produce capital goods more efficiently over time. Let q represent the time t state of technology for producing capital goods. Let q grow at the exogenous rate γ_q . This is the only source of real growth in the model.

$$k_{1t+1} = q_t i_t \quad (2.9)$$

Output can be used for consumption purposes or investment in new plants. Therefore, the aggregate budget constraint can be written as follows.

$$c_i + i_t = \sum_{i=1}^N \psi_i k_i^\alpha l_i^\omega \quad (2.10)$$

The static decision facing the firm manager concerns the allocation of labor across plants. Given k_i efficiency units of capital and taking the price level and

the nominal wage rate w as given, the plant manager maximizes plant profits.

$$\Pi_i(k_i, w) = \max_{l_i} \{pk_i^\alpha l_i^\omega - wl_i\} \quad (2.11)$$

The first order condition associated with this problem is

$$w = \omega pk_i^\alpha l_i^{\omega-1} \quad (2.12)$$

substituting this into (2.11) results in the profit function

$$\Pi_i(k_i, w) = p(1 - \omega) k_i^\alpha l_i^\omega \quad (2.13)$$

The dynamic decision facing the representative firm manager how much capital to place in the new plants. The firm pays wages out all of current revenues, but borrows from the financial intermediary at the nominal interest rate to finance investment expenditures. Any profits are payed out as dividends. An alternate setup would be to have the firm pay out a fraction of its profits as dividends and use retained earnings to finance renovations, but the results would be similar. Either way, the firm will incur an opportunity cost equal to the prevailing nominal interest rate r . The setup here is chosen for simplicity. This decision is in line

with the following dynamic programming problem. Note that primed variables indicate time $t + 1$ values.

$$V(k_1, \dots, k_N; s) = \max_{k'_1} \left\{ \sum_{i=1}^N \psi_i \Pi_i(k_i, w) - (1+r) \psi_1 k'_i + E_t \left\{ \frac{V^{(')}}{1+r} \right\} \right\} \quad (2.14)$$

subject to

$$k'_{i+1} = k_i \quad (2.15)$$

Equation (2.15) is the rule for capital accumulation. Age i capital today will be age $i + 1$ capital tomorrow. The first order condition associated with this problem is

$$(1+r) q \psi_1 = E_t \left\{ \frac{V_1^{(')}}{1+r'} \right\} \quad (2.16)$$

with

$$V_i^{(')} = \psi_i \Pi_i(k'_i, w') + E_{t+1} \left\{ \frac{V_{i+1}^{('')}}{1+r''} \right\} \quad (2.17)$$

Equation (2.16) determines the amount of capital to be placed in a new plant.

The cost of an extra unit of capital is $(1+r)q$ while the benefit is $V_1'(k_1)/(1+r)$ represents the derivative of the value function with respect to k_1 . This can be solved forward to yield

$$(1+r_t)\psi_1 = E_t \sum_{i=1}^N \left\{ \prod_{j=1}^i (1+r_{t+j})^{-1} \right\} \psi_i \Pi_{i1}(k_{t+i}, w_{t+i}) \quad (2.18)$$

This expression states that today's marginal cost of capital must equal the present value of value marginal products over its lifetime. This is much different from the standard first order condition for capital which only depends on the marginal product one period forward.

2.3. The Representative Consumer's Problem

Consumers have preferences defined over random streams of consumption and leisure represented by the expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t W(c_t, 1-l_t) \quad (2.19)$$

$$W(c, l; \lambda) = \ln \left(c - \lambda \frac{\Theta l^{1+\nu}}{1+\nu} \right)$$

where c represents consumption, l represents labor, $\beta < 1$ is the discount rate and E_0 represents the conditional expectation based on information available at time 0. The form of the utility function is justified by Greenwood, Rogerson, and Wright (1994) as being consistent with household production theory. The term λ represents the state of technology in the household production sector. Further, this form of utility allows the model's steady state to be independent from the distribution of wealth between the skilled and unskilled workers.

At the beginning of period t , the economy's money supply is held by consumers in the form of cash and deposits. One can think of cash as money held in a checking account which earns zero interest and deposits as money held in a savings account earning nominal interest $r_t > 0$. A key assumption is that the composition of an individual's portfolio is made in the previous period. Although cash earns no interest, it is required to purchase goods through the familiar cash in advance constraint

$$p_t c_t \leq m_t^c \tag{2.20}$$

At the end of the period, households receive income from four sources: wage income, interest earned on their savings, dividends from banks, and profits from

the production firm.

$$p_t y_t = w_t l_t + (1 + r_t) m_t^d + \Pi_t^b + \Pi_t^p \quad (2.21)$$

Money income can be allocated for consumption purposes or can be saved. Saved income is divided between a household's checking account and savings accounts

$$s_t = (m_{t+1}^c - m_t^c) + (m_{t+1}^d - m_t^d) \quad (2.22)$$

Where $m_{t+1}^d, m_{t+1}^c \geq 0$ (households can't issue money). Also, the household faces the budget constraint

$$p_t c_t + s_t = w_t l_t + (1 + r_t) m_t^d + \Pi_t^b + \Pi_t^p \quad (2.23)$$

the household's decision problem is to choose a contingency plan for

$\{c_t, l_t, m_{t+1}^c, m_{t+1}^d\}_{t=0}^{\infty}$ that maximizes expected lifetime utility subject to the

series of constraints.

The unskilled workers problem can be written in the following recursive formulation. Note that to save on notation, time subscripts have been left out. Primed

variables indicate their $t + 1$ values. s represents the state of the world which will be defined later.

$$J(m^c, m^d; s) = \underset{c, l, m^c, m^d}{Max} \left\{ \begin{array}{l} W(c, l) + \beta E_t J(m^c, m^d; s') \\ + \lambda_1 \left(\begin{array}{l} wl + (1 + r)m^d + \Pi^b + \Pi_t^p \\ -m^c - m^d \end{array} \right) \\ + \lambda_2 (m^c - pc) \end{array} \right\} \quad (2.24)$$

The upshot of the dynamic programming problem are the following first order conditions

$$W_1(c, l) = p\lambda_2 \quad (2.25)$$

$$-W_2(c, l) = w\lambda_1 \quad (2.26)$$

$$\beta E J_1(m^c, m^d, s') = \lambda_1 \quad (2.27)$$

$$\beta E J_2 (m^c, m^d, s') = \lambda_1 \quad (2.28)$$

Along with the following envelope conditions

$$J_1 (m^c, m^d, s) = \lambda_2 \quad (2.29)$$

$$J_2 (m^c, m^d, s) = (1 + r) \lambda_1 \quad (2.30)$$

Using the first order conditions along with the envelope conditions, the unskilled worker's problem can be reduced to the following two efficiency conditions.

$$\frac{W_2 (c, l)}{w} = \beta E \left\{ \frac{W_1 (c', l')}{p'} \right\} \quad (2.31)$$

$$\frac{W_2 (c, l)}{w} = \beta E \left\{ (1 + r) \frac{W_2 (c', l')}{w'} \right\} \quad (2.32)$$

Equation (2.31) is the efficiency condition for cash balances. On the left hand side is the marginal cost of obtaining one unit of cash in terms of foregone leisure time. That is, $1/w$ hours of work is required to earn one unit of cash. The marginal disutility of labor $W_2 (c, l)$ converts the hours into utility. The left hand

side of (2.31) is the expected benefit of the extra unit of cash in terms of the expected utility of the consumption it can purchase. Equation (2.32) is the efficiency condition for deposits. Deposits cannot be used for consumption, but can be used to purchase the credit good in this economy - leisure. Therefore, the left hand side of (2.32) is the marginal cost of obtaining an additional unit of deposits while the left hand side is the marginal benefit of the leisure time that can be purchased next period.

2.4. Financial Intermediaries

Financial intermediaries collect deposits from skilled workers and unskilled workers and loan the money out to firms. They also receive cash injections from the government. Denoting cash transfers by τ , the financial intermediaries profits are the difference between interest collected from the firm and interest paid out on deposits to consumers and can be written as

$$\begin{aligned}
 \Pi^b &= (m^d + \tau)(1 + r) - m^d(1 + r) \\
 &= (1 + r)\tau
 \end{aligned}
 \tag{2.33}$$

3. Equilibrium

The model is completed by a description of the state of the world. This is given by the vector $s = \{k_1, \dots, k_N, \mu_t, b_t, m\}$. Given the definition of the state, the competitive equilibrium can be defined as a set of decision rules $\{c, l, m^c, m^d, k_i\}$ and a set of pricing functions $\{p, r, w\}$ such that

1) Given their beliefs on the current policy regime, consumers optimize, taking interest rates, wages, and prices as given, resulting in decisions for consumption, labor, cash and deposits given by c, l, m^c, m^d

2) Given its beliefs on the current policy regime, the representative firms and all plants maximize profits taking interest rates, wages, and prices as given. The resulting decisions are represented by k'_1, l_i .

3) Beliefs are updated rationally using all available information via Bayes Rule.

4) Given the behavior of consumers and producers, prices adjust such that markets clear, as represented by the following conditions

$$\tau + m^d = pi_t \tag{3.1}$$

$$c + i_t = \sum_{i=1}^N \psi_i k_i^\alpha l_i^\gamma \tag{3.2}$$

$$\sum_{i=1}^N \psi_i l_i = l \quad (3.3)$$

$$m^{d'} + m^{c'} = m' \quad (3.4)$$

4. Balanced Growth

In this section the balanced growth properties of the model will be derived. This will be needed when the economy is transformed into one where all the variables are stationary. First of all, it is reasonable to assume that in the steady state, labor supply is constant. The aggregate budget constraint implies that consumption, investment, and output all grow at the same rate g .

Due to the increase in efficiency in producing capital goods, capital grows over time at a rate faster than investment..

$$\gamma_k = g\gamma_q \quad (4.1)$$

Given the production function, the growth of output can be calculated.

$$\gamma_y = \gamma_k^\alpha = (g\gamma_q)^\alpha \quad (4.2)$$

$$g = \gamma_q^{\frac{\alpha}{1-\alpha}} \quad (4.3)$$

Therefore, as the economy's efficiency at producing capital goods grows over time, the capital to output ratio rises over time. This is another fact documented in Greenwood, et al (1994). Note that for labor supply to be constant in the steady state, technology in the household production sector must grow at the same rate as consumption.

$$\gamma_\lambda = \gamma_c \quad (4.4)$$

Note that as the capital stock grows, the marginal value of capital for the firm declines. However, so does the marginal cost of new capital in terms of consumption.

With all the real variables accounted for, all that remains is to look at the nominal variables. The money market clearing equation implies that the growth of cash and deposit holdings by both skilled and unskilled workers equals the growth in money supply. The cash in advance constraint then restricts the growth

in the real value of cash holdings to equal the growth in consumption. It is then straightforward to show that the growth in the price level.

$$\gamma_p = \frac{\gamma_m}{\gamma_c} \quad (4.5)$$

where γ_m is the growth rate of money supply. Given the balanced growth properties, the model is reduced to the following transformed equations. A hatted variable represents the transformed analog to the variables given above.

4.1. Firms

Labor Demand

$$l_{it} = \left(\frac{\hat{k}_{jt}}{\hat{k}_{1t}} \right)^{\frac{\alpha}{1-\omega}} l_{1t} \quad (4.6)$$

Capital Accumulation

$$\begin{aligned} (1 + r_t) \psi_1 &= \left(\frac{\gamma_m}{\gamma_k} \right) E_t \left\{ \frac{\hat{V}_1(t+1)}{(1 + r_{t+1})} \right\} \\ \hat{V}_i(t+1) &= \psi_i \hat{\Pi}_k(t+1) + \left(\frac{\gamma_m}{\gamma_k} \right) E_{t+1} \left\{ \frac{\hat{V}_{i+1}(t+2)}{(1 + r_{t+2})} \right\} \end{aligned} \quad (4.7)$$

Capital Accumulation (for $i=2,\dots,N$)

$$\gamma_k \hat{k}_{it+1} = \hat{k}_{i-1t} \quad (4.8)$$

4.2. Unskilled Workers

Cash Holdings

$$\gamma_{mt} \frac{\Theta l_t^\nu}{\left(\hat{c}_t - \frac{\Theta l_t^{1+\nu}}{1+\nu}\right) \hat{w}_t} = \beta E_t \left\{ \frac{1}{\left(\hat{c}_{t+1} - \frac{\Theta l_{t+1}^{1+\nu}}{1+\nu}\right) \hat{p}_{t+1}} \right\} \quad (4.9)$$

Deposit Holdings

$$\gamma_{mt} \frac{\Theta l_t^\nu}{\left(\hat{c}_t - \frac{\Theta l_t^{1+\nu}}{1+\nu}\right) \hat{w}_t} = \beta E_t \left\{ \frac{(1 + r_{t+1})}{\left(\hat{c}_{t+1} - \frac{\Theta l_{t+1}^{1+\nu}}{1+\nu}\right) \hat{w}_{t+1}} \right\} \quad (4.10)$$

Cash in Advance Constraint

$$\hat{m}_t^c \geq \hat{p}_t \hat{c}_t \quad (4.11)$$

Budget Constraint

$$\hat{p}_t \hat{c}_t + \gamma_{mt} \hat{m}_{t+1}^c + \gamma_{mt} \hat{m}_{t+1}^d = \hat{w}_t l_t + (1 + r_t) \hat{m}_t^d + \hat{\Pi}_t^b + \hat{\Pi}_t^p \quad (4.12)$$

4.3. Financial Intermediary

$$\hat{\Pi}_t^b = (1 + r_t) \hat{\tau}_t \quad (4.13)$$

4.4. Money Supply

$$\frac{M_{t+1}}{M_t} = (1 + \mu_{mt}) = \gamma_{mt} \quad (4.14)$$

4.5. Market Clearing

Loan Market

$$\hat{\tau}_t + \hat{m}_t^d = \hat{i}_t \quad (4.15)$$

Goods Market

$$\hat{c}_t + \hat{i}_t = \sum_{i=1}^N \psi_i \hat{k}_{it}^\alpha \hat{l}_{it}^\omega \quad (4.16)$$

Unskilled Labor Market

$$\sum_{i=1}^N \psi_i \hat{l}_{it} = \hat{l}_t \quad (4.17)$$

Money Market

$$\hat{m}_t^d + \hat{m}_t^c = 1 \tag{4.18}$$

5. Calibration

The next step in the analysis is to choose values for the models parameters. The values come from either *a priori* information or so that along the model's balanced growth path various endogenous variables assume the long run values seen in the US. data.

technology: α ω γ_k

preferences: β ν Θ

policy: μ_L μ_H σ_L σ_H ψ φ_{ij}

A time period is chosen to correspond to one year. Over the post war period, labor's share of income has averaged .65. This implies that $\omega = .65$. The value of $1/\nu$ corresponds to a labor supply elasticity. Following Greenwood, Hercowitz and Huffman (1988), a value of .6 was chosen. This implies a value of 1.7 for the labor supply elasticity, which is an average found by earlier researchers.

The average growth rate of output per hour was 1.24 percent between 1954–90. Thus, the model should satisfy the property

$$\gamma_y = 1.0124 \quad (5.1)$$

The average ratio of hours to non sleeping hours of the working age population is .25. Therefore,

$$l = .25. \quad (5.2)$$

The nominal interest rate is chosen to be 9%. Assuming a long run rate of money growth of 5% yields the restriction for the discount rate.

$$\frac{\gamma_m}{\beta} = 1.09 \quad (5.3)$$

Using these restrictions implies the following parameter values

$$\alpha = .2$$

$$\omega = .65$$

$$\gamma_q = 1.06$$

$$\beta = .9633$$

$$\nu = .6$$

$$\Theta = .476$$

The parameter estimates for the process governing money growth are taken from Andolfatto and Gomme (1997) who estimated them via maximum likelihood using Hamilton's (1989) regime switching model to data on per capita money growth for Canada over the sample period 1955:1 - 1996:1. The parameter estimates are as follows.

<i>parameter</i>	μ_L	μ_H	σ_L	σ_H	φ_{LL}	φ_{HH}
<i>estimate</i>	.04	.08	.0104	.0077	.9922	.9637

6. Disinflationary Policy

The experiment studied here is a permanent switch from high money growth economy ($\mu_H = .08$) to a low money growth economy ($\mu_L = .04$). It should be noted that the results are symmetric for switching from a low growth economy to a high money growth. Since only permanent, non-stochastic policy experiments are being considered, the switching probabilities in the Markov process governing the monetary regime are set to zero. The main problem here is choosing an initial prior for the beliefs of consumers. In Andolfatto and Gomme, the choice for the initial prior was the steady state belief given that the switching process was as described above. Here, the initial prior is chosen simply as a parameter. The three experiments considered will be as follows. First, the governments announced

policy of lower money growth is fully credible. This corresponds to $b_0 = 1$ (the public is certain that the economy is in a low money growth regime). In the second experiment, the government doesn't have perfect credibility, but credibility is still high. In this experiment, the initial prior is set at .7 (consumers believe that there is a 70 percent chance that the monetary authority is committed to a low money growth regime). Finally, in the last experiment, the government is assumed to have low credibility. In this test, the initial prior is set at .2. Note that if the government had no credibility, ($b=0$), then no learning takes place and the central bank can "fool" the public forever. The solution mechanism used here is that of King, Plosser, and Rebelo (1987). The model is linearized around the steady state. The system of difference equations characterizing the model's dynamics has $N+1$ eigenvalues with modulus less than one. This corresponds to the model's $N+1$ state variables k_1, \dots, k_N and m^c . Therefore, the transition path is stable and unique. The modification here is in the calculation of the dynamic transition path that satisfies the transversality conditions. With complete information, the conditional expectation of future money growth is calculated as follows.

$$E[\mu_{t+1}/I_t] = \mu_i + \int f_H(\varepsilon_{t+1}) d\varepsilon_{t+1} ; i = L, H \quad (6.1)$$

With incomplete, information, we must take into account the role of beliefs. If consumers enter period t with belief b_t , the expectation of future money growth will be

$$E [\mu_{t+1}/I_t] = (1 - b_t) \left\{ \tilde{\mu}_H + \int f_H (\varepsilon_{t+1}) d\varepsilon_{t+1} \right\} + b_t \left\{ \tilde{\mu}_L + \int f_L (\varepsilon_{t+1}) d\varepsilon_{t+1} \right\} \quad (6.2)$$

and the evolution of b_t is given by

$$b_{t+1} = \frac{b_t f_L (\varepsilon_t)}{b_t f_L (\varepsilon_t) + (1 - b_t) f_H (\varepsilon_t)} \quad (6.3)$$

First off, it should be noted that expectations of future money growth (and, hence, future inflation) don't affect the optimality of new capital purchases directly. Take the first order condition for capital.

$$(1 + r_t) \psi_1 q_t = E_t \sum_{i=1}^N \left\{ \prod_{j=1}^i (1 + r_{t+j})^{-1} \right\} \psi_i (1 - \omega) p_{t+i} k_{it+i}^\alpha l_{it+i}^\omega \quad (6.4)$$

Using this and the relationship between the real and nominal interest rate

$$(1 + r_t) = (1 + \tilde{r}_t)(1 + \pi_t) = (1 + \tilde{r}_t) \left(\frac{p_{t+1}}{p_t} \right) \quad (6.5)$$

It is easy to show that the right hand side of the efficiency condition for capital is completely unaffected by money growth.

$$(1 + \tilde{r}_t)(1 + \pi_t) \psi_1 \left(\frac{q_t}{p_t} \right) = E_t \sum_{i=1}^N \left\{ \prod_{j=1}^i (1 + \tilde{r}_{t+j})^{-1} \right\} \psi_i (1 - \omega) k_{it+i}^\alpha l_{it+i}^\omega \quad (6.6)$$

In fact, the only place that money growth is involved directly is the nominal interest cost of capital expenditures. This is due to the fact that the firm must repay the financing for capital in the same period that the purchase is made. However, changes in money growth - particularly permanent changes - do affect investment through labor supply and future capital purchases. As in Stockman (1981), higher money growth (hence, higher inflation) has a negative impact on the steady state capital through the inflation tax on capital investment. Further, as in Cooley (1989), because workers can't convert their wages into cash until the following period, they pay an inflation tax as well. Therefore, higher money growth has a negative impact on labor as well as capital.

In the first experiment with complete information, the liquidity effect of the

decrease in money growth is very short lived. Figures 1.1-1.6 shows the dynamic transition paths following the policy change. Capital investment initially falls, but starts towards the new steady state one period following the shock. Investment expenditures are above the old steady state by the sixth period following the shock. Labor, output, and consumption fall for significantly longer (7 periods following the shock) and take longer to surpass the old steady state (14 periods). This is due to the fact that as investment expenditures remain below the steady state, the aggregate capital stock continually falls. Its not until new investment expenditures surpass the old steady state that the aggregate capital stock begins to rise to its new level.

In the second experiment, the initial prior was set to .7. With imperfect information, The effect on investment expenditures on impact is larger and the drop in investment is more persistent. Figures 2.1-2.6 show the dynamic paths following the drop in money growth. Investment falls for two periods and remains below the old steady state for 9 periods. As a result, labor, output and consumption fall for 9 periods and don't surpass the old steady state for 16 periods. Beliefs are plotted in figure 2.6. Notice that the public learns of the regime switch very quickly. By period 7 , consumers place a 100% probability of being in the low money growth state. This learning process could be slowed down by increasing

the variance of the error term in money supply.

In the third experiment, the initial prior was set to .2. With poor credibility, the public is "fooled" by the central bank for a longer period of time. Figure 6 plots the evolution of beliefs with $b_0 = .2$. With a lower initial starting value, consumers take longer to become confident that they are actually in a low money growth state. In this case the liquidity effect dominates the anticipated inflation effect for longer and the economy experiences a longer recession due to lack of liquidity in the financial sector. Figures 3.1-3.6 show the transition paths. As in the previous cases, on impact, the reduction in money supply initially creates a shortage of loanable funds in the financial sector, reducing investment. Note that the effect on impact is even bigger than in the previous two cases. Further, the public is "fooled" for a longer period. Figure 3.6 shows the evolution of beliefs. With low credibility, it takes the public 10 periods to fully trust the monetary authority.

7. Conclusions

Empirical evidence seems to support the premise that many central banks appear to alternate between distinct policy regimes associated with higher and lower rates of monetary expansion, possibly reflecting the attitude of the central banker

towards inflation. Further, many economists agree that a shortage of liquidity in financial markets due to unexpected decreases in money growth can drive up real interest rates and depress economic activity. The question addressed here is how a central bank's credibility affects the short run dynamics following a regime switch by the central bank. Earlier studies have shown that an unexpected regime switch to a low money growth economy, while generating long run benefits, create short run contractions.

Empirical studies at the microeconomic level show that plant level expenditures do not adjust smoothly as the standard neoclassical framework suggests, but are in fact "lumpy"- occurring infrequently and in bursts. This suggests that a model with vintage capital might be a more accurate representation of capital expenditures. Further, earlier authors have shown that technological progress which is specific to investment goods is an important source of growth in the US. economy. Prior studies of vintage capital economies have shown that the propagation mechanism of capital accumulation following an exogenous shock is greatly enhanced. The implication being that the welfare effects could be much larger than previously believed.

I construct a vintage capital model where new technology is embodied in new capital goods. The monetary transmission is introduced through a limited

participation setup where monetary injections do not coincide with individual's savings decisions. The resulting excess liquidity in the financial sector acts to drive down nominal interest rates and boost investment spending. Additionally, it is assumed here that the public has imperfect information as to the current policy regime. Therefore, they must learn from observations of money growth. This learning is undertaken in a Bayesian fashion. Results show that when the monetary regime has imperfect credibility with regard to regime switches, it takes time for the general public to believe the monetary authority's resolve. The consequences are that a switch to an anti-inflationary regime can initially generate a recession. Further, the less credibility a central bank has, or the less control the central bank has over the money supply (a larger random error term in the money supply process), the more prolonged is the contractionary period. Note that the knife here cuts both ways. The monetary authority faces a trade off between short run output effects and long run inflation effects. When the central banker can "fool" the general public, an unexpected switch to a higher money growth can generate a long lived expansion. This suggests that the welfare implications of monetary policy could be much larger than previously estimated.

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