Discussion Paper 118

Institute for Empirical Macroeconomics
Federal Reserve Bank of Minneapolis
250 Marquette Avenue
Minneapolis, Minnesota 55480-0291

July 1997

Monetary Policy Regimes and Beliefs

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ABSTRACT

Recent monetary history has been characterized by monetary authorities that appear to shift periodically between distinct policy regimes associated with higher or lower average rates of money creation. As policy regimes are not directly observable and as the rate of monetary expansion varies for reasons other than regime changes, the general public must form beliefs over current monetary policy based on historical realizations of money growth rates. Depending on the parameters governing the behaviour of monetary policy, beliefs (and therefore inflation forecasts) may evolve very slowly in the wake of actual regime changes, thereby exacerbating the costs of a disinflation policy. The quantitative importance of slowly adjusting beliefs is evaluated in the context of a computable general equilibrium model.

*We wish to thank Don Coletti, Wai-Ming Ho, Richard Rogerson, Randall Wright, as well as seminar participants at SUNY Buffalo, the Universities of Guelph and Rochester, the Bank of Canada, the Federal Reserve Banks of Atlanta, Chicago, and Cleveland, the British Columbia Macro Study Group, the SEDC meetings in Mexico City (1996), and the CMSG meetings in Kingston (1996). The financial support of SSHRC is gratefully acknowledged. The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

1. Introduction

Three observations motivate this paper. The first is that in many industrialized countries, central banks appear to shift periodically between distinct policy regimes that are associated with higher and lower average rates of monetary expansion. Consider, for example, monetary policy in Canada over the forty year period 1955–95 as depicted in Figure 1. Up until the early 1970s, the growth rate in monetary base was relatively low and stable, averaging around 2.7% per annum. The 1970s were characterized by sharply higher money growth rates, averaging in the neighbourhood of 8% per annum. Since the early 1980s, monetary policy seems to have tightened with money growth rates once again averaging around 3% per annum. The broader monetary aggregates share the secular movements displayed by the monetary base.

The second observation deals with the pattern of actual and expected inflation. From Figure 2, it appears that the rate of inflation shares a trend with the rate of growth in the monetary base, which suggests that monetary regimes might reflect the position of central bankers who are alternatively 'hard' or 'soft' on inflation. Actual inflation is somewhat 'sticky' in the sense that it displays less volatility than money-growth at higher frequencies. While expected inflation is somewhat difficult to measure, there is a consensus view (at least among central bankers) that inflationary expectations display a considerable amount of inertia in the sense of appearing (on the surface) to be unwarranted by the contemporaneous state of monetary policy (Thiessen, 1996). To the extent that expectations of inflation are reflected in the nominal interest rate, Figure 3 provides some evidence in support of this 'sticky expectations' hypothesis. In particular, note how long it took for interest rates to rise during the 'loose-money' regime of the 1970s, and how long it took for interest rates to fall during the 'tight-money' regime of the 1980s.

Third, as described by Friedman (1968), there appears to be a 'liquidity effect' associated with sharp changes in monetary policy. That is, in the short-term, a tightening of monetary policy is associated with an increase in interest rates and a contraction in economic activity. Consider again the experience of Canada as summarized in Figure 4. Monetary policy is widely thought to have contributed to the depth and the length of the 1981–82 recession (Howitt, 1986). The contemporary policy of reducing monetary base growth sharply in 1981 is blamed for the excessively high interest rates and depressed market activity experienced in that year. The persistence of the recession throughout 1982 and the slowness of the subsequent recovery are events generally attributed to the continued high rates of interest brought about by the central bank's ongoing program of monetary restraint in the face of persistently high expectations of inflation.[1] The inertia exhibited by inflationary expectations is commonly explained in terms of the historical pattern of monetary policy and the lack of central bank credibility. In particular, the loose-money regime of the 1970s had revealed that the monetary authority was willing and capable of generating high rates of inflation. Central bank proclamations of a commitment to long-term price-stability were made repeatedly since 1975, yet the rate of monetary expansion and inflation remained relatively high, straining the credibility of the central bank.[2] When Governor Bouey finally put the brakes on monetary expansion in 1981, it is likely that market participants wisely hedged their bets over whether the observed monetary restraint represented a true shift in regime or whether it simply represented a temporary deviation from the prevailing loose-money regime.

The question that concerns us in this paper is the following: What is the theoretical and empirical support for the explanation of events described above? The extent to which 'sticky expectations' based on the noncredibility of monetary policy might contribute to an extended period high interest rates and economic contraction in response to a disinflation policy has not been examined in the con-

[1]Other factors are also recognized as having contributed to the 1981–82 recession. For example, the fact that the recession was experienced worldwide meant that the demand for Canadian exports fell. At the same time, the relative price of basic commodities and energy fell substantially on world markets, leading to a deterioration of the terms-of-trade for Canada.

[2]From 1975–81, the Bank of Canada implemented a strategy called Gradualism, which was a program designed to gradually reduce the rate of growth of narrowly defined money (M1).

text of general equilibrium theory. The purpose of this paper is to develop a quantitative–theoretical framework that can be used to evaluate the likely empirical relevance of 'sticky expectations' in exacerbating the economic effects of shocks to monetary policy. Below, monetary growth rates are assumed to fluctuate owing to regime changes (i.e., shifts in the 'long run' money growth rate), and due to 'monetary control errors' (transitory fluctuations around the long run growth rate). For simplicity, we assume that there are only two regimes reflecting high and low 'long run' money growth rates, and that the regime switching process is exogenous; consequently, we ignore any strategic interactions that might arise between the general public and the monetary authority.[3]

We interpret the stickiness of inflationary expectations as reflecting slowly evolving beliefs on the part of individuals concerning the prevailing type of the monetary regime. In our model, central bank announcements pertaining to regime-type are considered to be inherently noncredible. This latter assumption is motivated by the fact that while long-run price level stability appears to be a regularly stated goal of the monetary authority, the willingness or ability of the central bank to meet this objective appears to fluctuate periodically, manifesting itself as prolonged periods of higher or lower average growth rates in base money.[4] Together with the presence of monetary control errors, the assumption of noncredibility implies that individuals in the economy can never know with absolute certainty which monetary regime is (or has been) in place. Instead, the public must resort to making inferences over regime type based on the observed history of realized money growth rates. Depending on the nature of the stochastic process governing money growth, and depending on the belief formation mechanism (we assume ra-

[3]Backus and Driffill (1985b) investigate the theoretical properties of a game played between a strategic public and monetary authority.

[4]Prolonged bursts in money growth likely arise from the belief that in the short run loose monetary policy can stimulate real economic activity. During such periods, the long run price level stability target evidently takes a back seat to more pressing immediate concerns. The burst in money growth is prolonged even after the short run stimulative effect on real output has passed because of a reluctance on the part of the monetary authority to induce the necessary contraction that follows monetary restraint.

tional expectations), adjustments in beliefs (and consequently inflation forecasts) may proceed very slowly, exacerbating the economic costs of a disinflation policy.

Our paper is related to a number of previous studies. The theoretical interaction between monetary policy, credibility and belief formation has been examined by Backus and Driffill (1985a) in the context of the Barro and Gordon (1983) policy game model. In their environment, central bankers are one of two possible types, labelled 'wet' and 'hard-nosed'. The public forms beliefs over the type of the central banker and updates those beliefs in a Bayesian manner, but regime shifts are not considered. Cukierman and Meltzer (1986) model a monetary authority with state-dependent preferences that shift stochastically over time in terms of the relative weights placed on inflation and economic activity. Because the public cannot observe the state of preferences directly, it must form inferences based historical money growth rates. The focus of their analysis is on why a monetary authority may choose ambiguous control procedures (i.e., introducing noise into the money growth process) even if it is able to determine freely the accuracy of monetary control. Laxton, Ricketts and Rose (1994) examine some of the quantitative implications associated with regime shifts when monetary policy is not fully credible. These authors develop a 'reduced-form' model that features expectations formed with a combination of backward-looking, least-squares learning, and Bayesian updating of beliefs about the credibility of alternative regimes. In both the historical estimates and model simulations, their framework identifies relatively long periods of systematic errors in expectations, especially when there are large shocks or changes in regime.

The approach taken below is to evaluate the sticky-belief hypothesis in the context of a computable general equilibrium model. The demand for money arises from a standard cash-in-advance constraint. The model incorporates a limited-participation feature along the lines of Lucas (1990) and Fuerst (1992). In particular, it is assumed that the division of money between cash and interest-bearing deposits by households cannot be conditioned on the contemporaneous realization of the monetary injection; in this manner, participation in the money-market is temporarily limited to firms and financial intermediaries. In this set-up, it is possible for a monetary injection to result in a temporary decline in interest rates, leading to increased output and employment. However, while the Lucas–Fuerst formulation can, in principle, generate a liquidity effect, Christiano (1991) has shown that for plausible parameterizations, it does not. The problem is that in addition to the liquidity effect, there is also an anticipated inflation effect: with positive autocorrelation in the money growth rate, a positive money surprise is also a harbinger of higher future inflation, which tends to depress economic activity. However, we have discovered that the interaction between regime changes and sluggish beliefs can generate a quantitatively important liquidity effect for plausible parameter values.

The main results of the paper can be summarized as follows. For plausible parameter values, it is demonstrated how the implementation of a credible disinflation policy will result in a period of economic expansion and lower interest rates, while the implementation of a noncredible disinflation policy will (for the same parameter values) result in recession and temporarily higher rates of interest. Interestingly, when information concerning the state of monetary policy is incomplete, the effects of an analogous expansionary monetary policy are shown not to be a symmetric mirror image of the disinflation policy. The calibrated model is then used to interpret the likely quantitative importance of noncredibility during the disinflation era of the early 1980s in Canada. It is estimated that the main impact of policy noncredibility was in keeping inflation forecasts and interest rates significantly higher than warranted by the true state of monetary policy. Furthermore, while monetary policy is estimated to a large negative impact on output growth in the second quarter of 1982, policy noncredibility per se likely contributed very little to the depth and length of the 1981–82 recession.

The paper is organized as follows. Section 2 develops the economic environment and describes a competitive equilibrium. Model calibration undertaken in

Section 3. The key results of the paper are reported in Section 4, which analyzes the behaviour of the model economy following a change in monetary regime. Section 5 reports the estimated welfare benefit of disinflation policy and in Section 6, the empirical relevance of policy noncredibility is evaluated for Canada in the context of the model. Section 7 reports the results of a sensitivity analysis. Section 8 concludes and offers suggestions for future research.

2. Model

2.1 Households

Time is discrete and denoted by $t = 0, 1, ..., \infty$. Individuals have preferences defined over random streams of consumption (C_t) and leisure (L_t) represented by an expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, L_t) \qquad 0 < \beta < 1 \tag{1}$$

where

$$U(C, L) \equiv \frac{[C^{\omega} L^{1-\omega}]^{1-\gamma} - 1}{1 - \gamma}.$$

The specification of the expectation operator E_0 will vary depending on the information structure assumed; this will be discussed in greater detail below. The household is endowed with one unit of time per period, which it divides between labour (N_t) and leisure;

$$N_t + L_t = 1. \tag{2}$$

At the beginning of period t, the economy's money supply M_t is held by households in the form of 'cash' M_t^c and 'deposits' M_t^d; i.e.,

$$M_t = M_t^c + M_t^d. \tag{3}$$

One can think of M_t^c as money held in a chequing account that earns zero interest and M_t^d as money held in a savings account (one-period term deposit) that earns nominal interest $R_t > 0$. A key assumption of the model, in terms of generating a liquidity effect, is that the composition of money holdings in the current period has been predetermined by a portfolio decision made in the previous period. A chequing account is held by households since cash is required to purchase consumer goods. In particular, there is a cash-in-advance constraint on consumption purchases given by

$$M_t^c \geq P_t C_t \qquad \text{for all } t, \tag{4}$$

where P_t is the price level.

At the end of period t, the household receives money income Y_t from three separate sources: wage income, interest income, and dividend income. Let W_t denote the nominal wage rate so that nominal wage income is $W_t N_t$. The household's term deposit generates interest income $R_t M_t^d$. Dividend income accrues from ownership in business sector equity, which comprises goods-producing firms and intermediaries. Let D_t^f and D_t^b denote dividends remitted by firms and banks, respectively.[5] Thus, end-of-period money income is given by

$$Y_t \equiv W_t N_t + R_t M_t^d + D_t^f + D_t^b,$$

and money balances evolve according to:

$$M_{t+1}^c + M_{t+1}^d = Y_t + M_t^d + (M_t^c - P_t C_t). \tag{5}$$

The household's decision problem is to choose a contingency plan

$$\{C_t, N_t, L_t, M_{t+1}^c, M_{t+1}^d \mid t \geq 0\}$$

that maximizes (1) subject to (2)–(5), given a stochastic process for

$$\{P_t, W_t, R_t, D_t^f, D_t^b \mid t \geq 0\}$$

and given $M_0^c, M_0^d \geq 0$, with expectations E_0 formed rationally under the assumed information structure.

[5]We assume, without loss, that shares in business sector equity are not traded.

2.2 Firms

Firms produce output Q_t with capital K_t and labour H_t according to a constant returns to scale production function F:

$$0 \leq Q_t \leq F(K_t, H_t), \tag{6}$$

where $F(K, H) = K^{\theta} H^{1-\theta}$. The capital stock is owned by the firm, but labour must be rented at wage W_t. Assume that firms must borrow money from a financial intermediary at interest rate R_t in order to finance their wage bill $W_t H_t$, but that firms are able to extend credit to each other for the purpose of financing capital expenditures I_t. After output is produced, consumer goods are delivered to households for cash, while capital goods are sold to firms (in effect, capital goods are retained as productive inventories by the business sector). Cash earnings do not arrive in time to finance the period wage bill. Consequently, after business loans to intermediaries are paid back and after capital expenditures are undertaken, the firm remits any remaining cash as a dividend payment to households;

$$D_t^f = P_t Q_t - P_t I_t - (1 + R_t) W_t H_t. \tag{7}$$

New capital goods I_t are used to augment the future capital stock in the business sector;

$$K_{t+1} = (1 - \delta) K_t + I_t, \tag{8}$$

where $0 \leq \delta \leq 1$ is the rate at which capital depreciates.

Firms choose a contingency plan $\{Q_t, H_t, I_t, K_{t+1}, D_t^f \mid t \geq 0\}$ to maximize the expected, discounted value of the dividend flow

$$E_0 \sum_{t=0}^{\infty} \Delta_{t+1} D_t^f$$

subject to (6)–(8), given a stochastic process for $\{P_t, W_t, R_t, \Delta_t \mid t \geq 0\}$ and given $K_0 \geq 0$, with expectations formed rationally under the assumed information structure. For firms to act in the best interests of their shareholders, the stochastic discount factor Δ_{t+1} should correspond to the representative household's relative valuation of cash across time, which requires

$$\Delta_{t+1} = \frac{\beta^{t+1} U_1(C_{t+1}, L_{t+1})}{P_{t+1}}.$$

2.3 Financial Intermediaries

At the beginning of period t, the financial intermediary sector receives a cash injection X_t from the monetary authority; this cash, together with the loanable funds M_t^d provided by households, is supplied inelastically to firms at interest rate R_t. The interest rate charged on loans is the same as that paid on deposits since financial intermediation is assumed to be costless and since there are no barriers to entry. Consequently, the financial sector earns profit

$$\begin{aligned} D_t^b &= (1+R_t)\left[M_t^d + X_t\right] - (1+R_t)M_t^d \\ &= (1+R_t)X_t \end{aligned} \tag{9}$$

which is remitted to households.

2.4 Monetary Policy

Monetary policy is exogenous. Let μ_t denote the growth rate of the money supply so that

$$M_{t+1} - M_t = \mu_t M_t = X_t,$$

with $M_0 > 0$ given. A *monetary policy regime* is associated with a 'long-run' rate of monetary expansion $\hat{\mu}_t$, where for simplicity we assume only two regimes:

$$\hat{\mu}_t \in \{\mu_L, \mu_H\}$$

with $\mu_L < \mu_H$. Monetary policy regimes switch back and forth over time according to a Markov transition law with known parameters:

$$\phi_{ij} = \Pr[\hat{\mu}_t = \mu_j \mid \hat{\mu}_{t-1} = \mu_i] \quad i,j = L, H. \tag{10}$$

Of course, $\hat{\mu}_t$ represents a 'long-run' money growth rate only to the extent that ϕ_{LL} and ϕ_{HH} are in some sense 'close' to unity.

Monetary growth is assumed to fluctuate within each regime according to a stationary first-order Markov process (representing monetary control errors) so that actual money growth evolves according to:

$$\mu_t = (1-\psi)\hat{\mu}_t + \psi\mu_{t-1} + \epsilon_t \tag{11}$$

with $|\psi| < 1$ and where ϵ_t is a random disturbance drawn from a Normal distribution function $N(0, \sigma_i)$, with density denoted by $f_i(\epsilon)$ for $i = L, H$.

2.5 Information Structure

Below, we consider two information structures that are distinguished by whether or not individuals are assumed to observe regime types. Under *complete information*, an individual's information set at date t includes the set

$$\Omega_t = \{\hat{\mu}_t, \hat{\mu}_{t-1}, \hat{\mu}_{t-2}, ...\};$$

that is, individuals are assumed to know which monetary policy regime is and has been in place. Under *incomplete information*, individuals are unable to observe the regime-type so that Ω_t is not a part of the information set.

2.6 Competitive Equilibrium

A competitive equilibrium for this model economy is defined in the usual way. Given a stochastic process for prices $\{P_t, W_t, R_t, \Delta_t \mid t \geq 0\}$ and given the behaviour of the government sector, households and firms form rational expectations (consistent with available information) and choose

$$\{C_t, N_t, L_t, M^c_{t+1}, M^d_{t+1}, Q_t, H_t, I_t, K_{t+1}, D^f_t, D^b_t \mid t \geq 0\}$$

optimally. In a competitive equilibrium, these choices are required to be consistent with the following market-clearing restrictions:

$$Q_t = C_t + I_t$$

$$
\begin{aligned}
M_t &= M_t^c + M_t^d \\
M_t^d + X_t &= W_t H_t \\
N_t &= H_t,
\end{aligned}
$$

which represent the goods, money, loans and labour markets, respectively.[6]

It is instructive to review some of the properties of the competitive equilibrium by considering, for example, how the economy reacts to an unanticipated reduction in the rate of money creation. Generally speaking, there are two basic economic forces at work that respond to such a disturbance; these forces have been labelled the *anticipated inflation effect* (or the Fisher effect) and the *liquidity effect*. Below, we discuss both effects in turn.

To the extent that money growth rates are positively serially correlated, the unanticipated reduction in money growth signals the likelihood of lower money growth rates in the future, leading individuals to revise downward their forecasts of future inflation. Since inflation acts as a tax on labour earnings, the anticipation of lower inflation increases the expected return to working and hence leads to an increase in the supply of labour (for any given real wage). At the same time, lower expected inflation implies a lower nominal interest rate through the Fisher effect, which has the effect of increasing the demand for labour (at any given wage). As both the supply and demand for labour rise in response to the anticipated inflation effect, the labour input and hence output expands, while interest rates fall.

The liquidity effect generates forces that work in the opposite direction. The unanticipated reduction in money growth means that the period cash injection from the monetary authority is lower than expected, leading to an unanticipated shortfall of loanable funds. Consequently, goods producing firms are induced to bid up interest rates in an attempt to secure the cash loans that they need in order to finance the period labour input. Normally, rising interest rates would

[6] The appendix provides a detailed account of the restrictions characterizing the model's equilibrium.

induce a portfolio substitution on the household side: individuals would want to economize on cash balances and increase their deposits at financial intermediaries. However, to the extent that households do not respond instantaneously to changes in monetary policy (as is assumed in the environment above), this response is ruled out (at least, temporarily). Thus, interest rates rise leading to a fall in labour demand and a decline in output. In this way, the liquidity effect causes output to contract and interest rates to fall, an effect that is opposite from the anticipated inflation effect. In equilibrium either effect may dominate depending on the configuration of the model's parameter values.[7]

2.7 Beliefs

When monetary policy is noncredible, individuals are compelled to infer the nature of the true regime based on any relevant information at their disposal. Given the exogenous nature of monetary policy, it is clear that the only information useful for inferring regime-type will be based on the known parameters governing money growth rates and on observations of current and past money growth rates $\Gamma_t = \{\mu_t, \mu_{t-1}, \mu_{t-2}, ...\}$, together with any prior information.

Let $b_t \equiv \Pr[\hat{\mu}_t = \mu_L \mid \Gamma_t]$ denote the probability that an individual assigns to the current regime being a tight-money regime, based on information Γ_t. Assume that b_0 is given and common across all individuals. Individuals are assumed to enter period t with belief b_{t-1} (which has been formed on the basis of information Γ_{t-1} and b_0); individuals then observe μ_t, update their beliefs and undertake their economic decisions. Under rational expectations, the belief sequence $\{b_t\}$ will obey the recursion (Bayes' rule):

$$b_t = \frac{g_L(b_{t-1}, \mu_t)}{g_L(b_{t-1}, \mu_t) + g_H(b_{t-1}, \mu_t)} \tag{12}$$

[7] See Christiano (1991) for further details.

where

$$g_L(b_{t-1}, \mu_t) \equiv [b_{t-1}\phi_{LL} + (1 - b_{t-1})\phi_{HL}]\, f_L(\mu_t - (1-\psi)\mu_L - \psi\mu_{t-1})$$
$$g_H(b_{t-1}, \mu_t) \equiv [b_{t-1}\phi_{LH} + (1 - b_{t-1})\phi_{HH}]\, f_H(\mu_t - (1-\psi)\mu_H - \psi\mu_{t-1}).$$

The function g_L is the product of two terms: the first term (in square brackets) is the probability (based solely on prior information b_{t-1}) that an individual attaches to a tight-money regime being in place in the current period while the second term represents the probability of observing the current money growth realization μ_t from the tight-money regime. Consequently, g_L represents the probability of observing the current realization μ_t from the tight-money regime conditional on prior information b_{t-1}. The function g_H has an analogous interpretation.

There are several things to note about beliefs. First, the statement that an individual believes that the central bank is, say, a tight-money type should be interpreted as meaning that the individual assigns a higher probability to the central bank being a tight-money type than a loose-money type. Provided that *all* the probabilities in (12) lie strictly between 0 and 1, an individual will never be absolutely certain as to the central bank's type.

Second, learning *will* occur. For example, suppose that at time t an agent assigns a high probability to the tight-money regime ($b_t \simeq 1$). Further suppose that the true regime is loose-money. Given a sequence of money growth rates that are more likely to have been generated by the loose-money regime, Bayesian updating implies that the individual's belief will begin to fall. For a long enough sequence, an individual's confidence in the tight-money regime will eventually approach zero.

Third, an agent may believe that he is currently dealing with a loose-money central banker, while the central banker may in fact be a tight-money type. On the one hand, an individual may correctly believe that he has been dealing with a loose-money central banker, but the central banker type may have recently changed and the individual has not yet seen enough low money growth rates to infer a change in policy. On the other hand, the central banker may be a tight-money type, but by chance there have been a series of relatively high realizations of money growth rates. Thus, individuals may incorrectly infer a change in monetary policy when there has, in fact, been none.

Notice that, depending on the parameters governing the rate of monetary expansion, beliefs about regime-type may adjust very slowly. Because inflation forecasts will depend on beliefs over the state of monetary policy, expectations of inflation may therefore exhibit some sluggishness as well. As such, the anticipated inflation effect described in subsection 2.6 will tend to be muted in response to surprise changes in monetary policy, an effect that may have important economic consequences, for example, with respect to the net welfare benefit of undertaking a disinflation policy.

3. Calibration

The parameters of the model are given by

Preferences:	β, ω, γ
Technology:	θ, δ
Monetary Policy:	$\mu_L, \mu_H, \phi_{LL}, \phi_{HH}, \psi, \sigma_L, \sigma_H.$

The parameters for preferences and technology are assigned values that are standard in the real-business-cycle literature (e.g., Prescott, 1986). In particular, assuming quarterly time periods, model calibration requires $\beta = 0.99$, $\omega = 0.275$, $\gamma = 1.5$, $\theta = 0.36$, and $\delta = 0.025$.

The parameters governing the money growth process are estimated via maximum likelihood by applying Hamilton's (1989) regime switching model to data on per capita base-money growth for Canada over the sample period 1955:2–1996:1. In estimating these parameters, the econometrician is assumed not to observe the shifts between regimes; instead, probabilistic inferences (beliefs) must be made based on the observed behaviour of the series.[8]

[8] As in the Kalman filter, one is using the time path of an observed series to draw inferences about an unobserved state variable. While the Kalman filter is a linear algorithm for generating

The actual estimation was undertaken with a GAUSS program written by Hamilton. This particular program does not estimate all of the parameters of interest in a direct manner. In particular, the code delivers estimates for $\mu_L, \psi, \sigma_L, \sigma_H$ together with $\alpha_1, \alpha_2, \alpha_3$ where these latter variables are related to the parameters of interest according to:

$$\begin{aligned} \mu_H &= \mu_L + \alpha_1 \\ \phi_{LL} &= \exp[-(\alpha_2)^2] \\ \phi_{HH} &= \exp[-(\alpha_3)^2]. \end{aligned}$$

The parameter estimates are as follows:[9]

Parameter:	μ_L	μ_H	ϕ_{LL}	ϕ_{HH}	ψ	σ_L	σ_H
Estimate:	0.0077	0.0267	0.9922	0.9637	0.2514	0.0104	0.0077
Standard Error:	0.0013				0.0846	0.0007	0.0011
Parameter:		α_1	α_2	α_3			
Estimate:		0.0190	0.0886	0.1925			
Standard Error:		0.0024	0.0464	0.0862			

The estimation procedure appears to identify long-term trends in the growth rate of per capita base money (as opposed to a trend that shifts at business cycle frequencies). The sample likelihood is maximized by tight-money growth rate of 0.77% per quarter (3.12% per annum) and a loose-money growth rate of 2.67% per quarter (11.12% per annum). The average duration of a loose-money regime is estimated to be $(1 - 0.9637)^{-1} \approx 28$ quarters, while the average duration of a tight-money regime is considerably longer at $(1 - 0.9922)^{-1} \approx 128$ quarters. The first-order serial correlation in money growth (for either regime) is estimated to be 0.2514, which contrasts with a common estimate of around 0.55 for linear models. It is interesting to note that the Gaussian component of money growth exhibits a

estimates of a continuous unobserved state variable, the Hamilton filter is a nonlinear algorithm and provides inferences over an unobserved discrete-valued variable.

[9] The initial belief b_0 was set equal to it's unconditional mean: $(1 - \phi_{HH})/(2 - \phi_{LL} - \phi_{HH})$.

higher percentage volatility in the tight-money regime. In particular, the standard deviation in the innovation to money growth in the loose-money regime is 0.77% compared to 1.04% for the tight-money regime. For these parameter estimates, the standard deviations for the 'monetary control' error in the loose-money and tight-money regimes are 0.80% and 1.08%, respectively. Thus, the 'noise' around each regime is small relative to the difference between average money growth in each regime $(2.67\% - 0.77\% = 1.90\%)$.

Figure 5 depicts the actual money growth series together with the estimated belief that the monetary authority is following a tight-money program at any given date, conditional on currently available information. Throughout most of the sample period, Bayesian individuals would have displayed a high degree of confidence in their inferences about regime-type. Over the 1955–71 sample period, belief in the tight-money regime rarely dipped below 75%. By 1972, persistently high money growth realizations had persuaded individuals that the monetary authority had switched to a loose-money policy–a belief that remained fairly entrenched until around mid-1979. The subsequent two years appear to be characterized by a considerable amount of uncertainty on the part of market participants in terms of exactly which monetary regime was thought to be in place. In late 1979 and early 1980, relatively low money growth realizations induced a rising belief in the tight-money regime, but a burst of high money growth in 1980 dashed this perception. As money growth fell in early 1981, belief in the tight-money regime again began to grow; by late 1981, with the per capita money supply actually contracting, confidence in the tight-money regime is estimated to have been well-established. Belief in the tight-money regime appears to have remained strong throughout the remainder of the sample.

4. Results

4.1 Transitory Shocks

Figure 6 displays the dynamic impulse response functions of the complete information model to a one-standard-deviation shock in the growth rate of money in the tight-money regime. In the impact period of the shock, the interest rate falls by about 2.5 percentage points while output rises by almost 0.5 percent (relative to its long-run level in the tight-money regime). However, the economy's adjustment to the shock is almost fully complete only one period later. Thus, on impact at least, the model is able to generate a significant liquidity effect. It is interesting to note how this result differs from that reported in Christiano (1991), where a similar experiment yields a rise in interest rates and a reduction in output. For the parameterization considered by Christiano, the anticipated inflation effect of a monetary disturbance evidently outweighs the liquidity effect. One likely explanation for Christiano's result is his specification of a relatively high value for the autoregressive coefficient on money growth (between 0.32 and 0.80), which is demanded by empirical plausibility, given his assumed structure for the monetary disturbance.[10]

The dynamic response of our model economy to a transitory monetary disturbance under incomplete information is virtually indistinguishable from the complete information case (there is a slight difference in the second period of the shock). Examining the evolution of beliefs in Figure 6 reveals why this is the case. Given that the economy has settled into a long-run associated with a tight-money policy, the transitory increase in money growth is interpreted by individuals for what it is: a short-lived monetary control error. Thus, confidence in the tight-money regime falls, but not by much quantitatively.

4.2 Disinflation Policy

In this section, the quantitative effects of a change in regime are examined. The precise nature of the exercise is as follows. Decision rules for the model economy

[10] In our estimated monetary growth process, there are two sources of persistence: (1) within-regime persistence as modelled by the AR coefficient ψ; and (2) the persistence of regimes as modelled by the transition probabilities ϕ_{HH}, ϕ_{LL}. Christiano (1991) attributes all persistence to the AR coefficient.

are obtained using the computational procedure described in the appendix, with all stochastic elements in play. During a simulation, the stochastic nature of the monetary control shock is suppressed and the monetary regime is forced to remain in one regime. The economy is then allowed to settle into a stationary state. In period ten, there is a regime shift (loose-money to tight-money, or vice-versa). The time series behaviour of key aggregate variables is then recorded under the assumption that the new regime remains in place indefinitely (of course, individual decision rules continue to incorporate the possibility of future regime changes as well as other monetary disturbances).

In this section, we focus on the regime change associated with a disinflation policy, under both complete and incomplete information. Results for this experiment are displayed in Figures 7–9. The bottom panel of Figure 7 reveals that this disinflation policy has a very different impact on output growth depending on the structure of information. In the complete information case, the disinflation policy generates a short-lived economic boom, with output growth peaking at 4% above trend two quarters following the change in monetary policy. In contrast, when monetary policy is noncredible, the disinflation policy actually induces a short-lived recession, followed by an economic boom lasting over five quarters and peaking in the third quarter following the change in monetary policy. The top panel of Figure 7 shows how confidence in the new regime evolves: it takes three quarters for agents to believe, on balance of probability, that the regime is a tight-money regime.

Figure 8 records the level effects on labour market variables of the disinflation policy (measured as percent deviations from their long-run levels associated with the loose-money regime). Under complete information, the labour input expands rapidly to its new long-run level, which is about 2% higher than under the loose-money regime. As labour expands relative to the capital stock, labour productivity falls accordingly. The real wage initially drops somewhat and then rises to a level slightly above its initial steady-state level. To understand why the real wage rises while labour productivity falls, recall that the demand for labour depends negatively on the nominal interest rate. Thus, while a lower inflation tax increases the supply of labour, the lower interest rate also increases the demand for labour. If the latter effect dominates, then the real wage will rise. Under incomplete information, the dynamic response of the labour input and productivity are initially quite different than under complete information (although the real wage behaves similarly). On impact, employment falls by almost 1% while productivity rises by about 0.3%; each of these variables then take about a full year to reach their new steady-state values.

Figure 9 traces the evolution of the nominal interest rate, the inflation rate, and the one-period-ahead forecast of inflation following the disinflation policy. Under complete information, the interest rate initially rises by 0.56% points, but then quickly falls to its lower steady-state value. On impact, the policy change actually induces a short-lived deflation, an event that is brought about by the suddenly lower rate of money expansion together with an expansion in the rate of output growth. Notice that expectations of inflation adjust very rapidly.[11]

The short run dynamics in the incomplete information case differ considerably from the complete information scenario. On impact, the nominal interest rate rises by 2.8% points and remains above its previous stationary value for two full quarters, displaying a relatively more sluggish transition to its long run value. Relative to the complete information case, inflation appears to be 'stickier'. The reason for this is because the contraction induced by the change in policy serves to keep prices high. Finally, observe that expectations of inflation evolve sluggishly relative to the complete information case.

4.3 Expansionary Monetary Policy

In this section we will examine the effects of switching from a tight-money

[11]Also note that expected inflation does not correspond to actual inflation even in the 'long-run' states of the economy. The reason for this is because individuals continue to attach some probability to a regime change.

regime to a loose-money regime; the results are recorded in Figures 10 and 11. Consider the response of output growth to this inflation policy (bottom panel of Figure 10). Under complete information, it appears that the effect is virtually the mirror image of the events following a disinflation policy. Interestingly, under the incomplete information case, the quantitative effect is *not* the mirror image of a disinflation policy. For example, in the impact period of the shock, output growth rises by over 2%, while in the impact period of the disinflation policy, output growth fell by less than 2%. More dramatic differences are to be found in the relative transition dynamics. In particular, recall that under the disinflation policy, output growth peaked at over 2% in the third quarter following the policy change; under the inflation policy, output growth bottoms out at about −2% five quarters following the policy change.

This experiment reinforces the observation that slow adjustment of beliefs lies at the heart of the differences in the short run dynamics between the complete and incomplete information versions of the model (compare Figures 7 and 10). Under the inflation policy, beliefs take significantly longer to adjust than under the disinflation policy. The intuition for this result lies in the estimated transition probabilities. Recall that the quarterly probability of remaining in the loose-money regime is just over 96%, while the probability of remaining in the tight-money regime is over 99%. Thus, regime changes are more likely to occur under the loose-money regime. Consequently, in a loose-money regime, Bayesian individuals are more inclined to interpret low money growth realizations as indicating a probable regime change. Under a tight-money regime, the probability of a regime change in any quarter is extremely unlikely; consequently, individuals are more reluctant to interpret high money growth realizations as reflecting a change in regime: relatively more realizations are required for individuals to become convinced of a regime change in this latter case.

Figure 11 records the impact of the inflation policy on the money market variables. Under complete information, the interest rate, inflation rate and expected inflation rate are all mirror images of the disinflation policy. In contrast, under incomplete information, the dynamics are drawn out considerably relative to the disinflation policy. In particular, notice that the nominal interest rate falls on impact and takes a full year before rising beyond its initial value; under the disinflation policy, the nominal interest rate rose on impact and took only half a year before falling below its initial value. Finally, observe that when information is incomplete, the inflation policy results in negative (ex post) real rates of interest lasting for about five quarters.

5. Welfare Analysis

In this section, we attempt to measure the welfare benefit of implementing a disinflationary policy. To begin, imagine that the economy has settled into a 'long-run' situation consistent with the loose-money regime having been in place for a long period of time. Now, imagine that the loose-money regime actually remains in place for the foreseeable future (e.g., 5000 quarters); let (c_t^H, ℓ_t^H) denote the consumption-leisure decisions made by individuals in response to such a realization.[12] The utility payoff of such a realization is given by:

$$V^H = \sum_{t=1}^{5000} \beta^{t-1} U(c_t^H, \ell_t^H).$$

The payoff V^H can be computed for both the complete and incomplete information environments.

Now, suppose that in the same long-run situation, the monetary regime actually switches to a tight-money regime for the next 5000 periods. Let (c_t^{HL}, ℓ_t^{HL}) denote the equilibrium consumption-leisure decisions associated with this realization and let y_t^{HL} denote the realized per capita output. The utility payoff of such

[12] Clearly, the realized sequence of consumption and leisure will in this case be constant (the monetary control errors are also suppressed) Note, however, that individuals still anticipate the possibility of a regime change at each date.

a realization is given by:

$$V^{HL}(\lambda) = \sum_{t=1}^{5000} \beta^{t-1} U(c_t^{HL} - \lambda y_t^{HL}, \ell_t^{HL})$$

when $\lambda = 0$. Our measure of the welfare benefit of switching (permanently) from the loose-money regime to the tight-money regime is given by the unique value of λ solving:

$$V^{HL}(\lambda) = V^{H}.$$

The parameter λ represents the fraction of income that an individual would (in retrospect) have been willing to sacrifice for the opportunity of living with the disinflation policy.

	Welfare Benefit ($\lambda \times 100$)
No Transitional Dynamics	0.2488
Complete Information	0.0768
Incomplete Information	0.0717

The above table summarizes the welfare benefit of switching to a tight-money regime. For comparison with previous literature, the welfare benefit is also calculated ignoring transitional dynamics. To begin, notice that the welfare figures computed across 'long-run' states are in the neighbourhood of those reported in the literature (e.g., Cooley and Hansen, 1989); i.e., around 0.25% of income (in perpetuity) for the 7.6 percentage point fall in inflation (from 10.7% to 3.1%). Accounting for the transitional path has a significant impact on the measured welfare benefit of disinflation. Compared to either the complete or incomplete information cases, ignoring transitional effects overstates the welfare benefit by over a factor of three. Thus, the already modest estimates of the welfare costs of inflation reported in the literature are likely overestimates. Finally, notice that the welfare benefit of a disinflation under incomplete information is lower than under complete information, which is to be expected since under incomplete information it takes individuals longer to figure out that a regime change has actually occurred. However, the quantitative costs of noncredibility are estimated to be small.

6. The Role of Noncredible Monetary Policy: 1979–1984.

In Canada, the late 1970s and early 1980s was a period that witnessed a transition from a high-inflation environment to a low-inflation environment. As mentioned earlier, a shift in monetary policy is generally credited with this development; but monetary policy is also held partly responsible for the contraction in economic activity experienced in the early 1980s as well as for the extended period of high interest rates prevailing in that decade. In this section, we attempt to evaluate the likely empirical relevance of noncredible monetary policy in Canada over this historical period in the context of the quantitative theory developed above.

In the experiments undertaken below, the actual money growth process for Canada over this time period is treated as a realization from the estimated stochastic process governing monetary policy. This realization is then used in conjunction with the equilibrium decision rules to compute the predicted time path of key economic aggregates under each of the complete and incomplete-information versions of the model. Any discrepancy that exists between the predictions of these two versions of the model is then treated as an estimate of the quantitative importance of noncredibility.

As regime-type is not observable, the predictions of the model under complete information must be conditioned on the date at which monetary policy is assumed to have switched. In the analysis below, two such dates are considered: the fourth quarter of 1979 and the first quarter in 1981. These dates are chosen on the basis of the estimated behaviour of beliefs. In particular, at both of these dates, belief in the tight-money regime began to grow significantly. In the former case, confidence in the tight-money regime began to decline somewhat after the initial rise, but it is unclear whether this decline was attributable to some unfortunate monetary control errors that occurred in the tight-money regime, or whether the growing confidence in the tight-money regime in early 1980 was mistakenly made on the basis of some unlikely monetary control errors generated by the loose-money regime.

Figure 12 plots the predicted path for output growth (deviation from trend), interest rates, expected inflation and beliefs for the incomplete information model. Given the pattern of money growth realizations, the model predicts a moderate boom in early 1980, close to trend growth over late 1980 and 1981, followed by some rather severe fluctuations in 1982. In the second quarter of 1982, annual growth in real per capita output in the model falls close to ten percentage points below trend growth, an event that the model attributes to the ten percent contraction in the supply of money that occurred in that quarter. Interest rates remain high on average throughout most of the sample period, showing temporary declines in 1980:2 and 1982:1, followed by a more persistent decline by the third quarter of 1982. Inflation forecasts began to decline in the latter part of 1979, but a burst of relatively high money growth realizations during 1980 caused inflation expectations to rise again. In 1981, a series of relatively low money growth rates resulted in a gradual decline in inflation expectations as individuals became confident that the tight-money regime was in place.

Figure 12 also plots the pattern of output growth, interest rates and inflation expectations predicted by the complete information model under the assumption that the actual regime change occurred in the third quarter of 1979. The model estimates little difference in output growth had monetary policy been fully credible. The most significant impact of a credible monetary policy would have been on the behaviour of interest rates and inflation expectations. Under a fully credible regime change in 1979:4, the model predicts that the annual interest rate would have been on average four percentage points lower throughout the 1980–81 period. Although interest rates are predicted to remain high through the better part of 1982, this is true for both information structures: the model attributes the high interest rates prevailing over this latter period to the shortfall in liquidity following some unusually low money growth realizations in that period and not to the lack of policy credibility.

In Figure 13, the model's predictions are again reported under both information structures, but now with the assumption (for the complete information model) that the regime change actually occurred in the first quarter of 1981. In this scenario, as in the first, noncredibility appears to have only a negligible impact on real output growth. However, the model suggests that in this case, interest rates over the 1979–80 period would have actually been higher under a credible monetary policy, since individuals would have realized that the loose-money regime was still in place while under noncredible policy, individuals would have mistakenly inferred the likelihood of a regime change. Once the regime change does take place, credibility implies that interest rates fall quickly while under noncredibility, interest rates remain higher than warranted by the true state of monetary policy throughout 1981. The economic consequences of noncredibility are estimated to have been fully dissipated by early 1982.

7. Sensitivity Analysis

In this section, we consider briefly how the model's dynamic properties depend on the parameters describing monetary policy. The experiment focuses on a disinflation policy undertaken in the incomplete information model. Figures 14 and 15 record the dynamic response of output growth and the nominal interest for different parameter values $\mu_H, \phi_{HH}, \phi_{LL}, \psi, \sigma_L$, and σ_H.

The first experiment entails reducing μ_H by 50% and 100%, respectively, from its benchmark value. Since μ_L is being held constant, the effect of this parameter change is to lessen the distinction between the two policy regimes. In addition, because the variance of the monetary control errors is held constant, the effect of this parameter change is to increase the difficulty in ascertaining changes in regime. Figure 14a reveals that lowering μ_H implies that a disinflation policy has a smaller impact effect on output growth, but a more moderate and prolonged dynamic effect. Figure 14b demonstrates that the while a lower μ_H implies a lower initial interest rate, the transition to the new steady-state interest rate can be prolonged considerably.

The second experiment considers varying the transition probabilities between regimes. In the experiment considered here, new transition probabilities are set to a common value, i.e., $\phi_{HH} = \phi_{LL} = \phi$ and then consider lowering ϕ to 0.90 and 0.80. The effect of lowering ϕ is to increase the probability of a regime change or, equivalently, to diminish the persistence exhibited by monetary policy regimes. From Figure 14c, the effect of making regimes less persistent is to make output respond as if it is responding to a transitory change in money growth. The effect of this parameter on the interest rate is as follows. On the one hand, interest rates start out high if regimes are persistent since individuals are forecasting continued high rates of inflation. When a regime change does occur, however, interest rates eventually fall to a much lower steady-state. As regimes become less persistent, the initial interest rate falls. The reason for this latter result is because the greater probability of a regime change translates into a lower expectation of inflation when one perceives to be in the loose-money regime. However, when a regime change does occur, the fall in the interest rate is not nearly as dramatic since, when regimes are less persistent, there is now a greater chance of a switch back to a loose-money regime, an effect that keeps inflation forecasts relatively higher in the tight-money regime.

In the third experiment, the persistence of the monetary control error is varied. As expected, when the monetary control error is transitory, individuals are more inclined to interpret the disinflation policy as a transitory disturbance in the impact period, but will learn relatively quickly about the true nature of the new regime. Consequently, output contracts relatively deeply on impact, followed by a robust economic boom; see Figure 15a. As persistence in the monetary control error is increased, the disinflation policy is more likely to be confused with a persistent deviation in the loose-money regime. Consequently, output falls by less in the impact period and displays a prolonged moderate boom as individuals slowly come to recognize the regime change. Figure 15b reveals that the adjustment period for interest rates is prolonged as persistence is increased.

In the final experiment, we double and triple the standard deviation of the innovations to the monetary control error. As the noise in the monetary control error is increased, individuals are less likely to attribute a sudden reduction in money growth to the possibility of a regime change. As Figure 15c demonstrates, the response of output growth to the implementation of a disinflation policy resembles the response of output to a transitory money shock. According to Figure 15d, the adjustment period for the interest rate can be greatly extended as individuals learn only very slowly of the regime change.

8. Conclusion

This paper has explored some of the theoretical and quantitative properties of a dynamic general equilibrium model that features stochastic regime changes in monetary policy under alternative information structures reflecting extreme views on policy credibility. For empirically relevant parameter values, it was demonstrated how the implementation of a credible disinflation policy resulted in a period of economic expansion and lower interest rates, while the implementation of a noncredible disinflation policy resulted in recession and temporarily higher rates of interest. When the model was used to interpret the disinflation era of the early 1980s in Canada, it was estimated that the main impact of policy noncredibility was in keeping inflation forecasts and interest rates significantly higher than was warranted by the true state of monetary policy. Furthermore, while monetary policy was estimated to have had a large negative impact on output growth in the second quarter of 1982, policy noncredibility per se likely contributed very little to the depth and length of the 1981–82 recession.

The analysis above is obviously very exploratory in nature; a number of interesting directions for future research are immediately apparent. To begin, the limited participation model of money utilized above makes some rather extreme assumptions concerning the ability of individuals to substitute into and out of cash; see Dotsey and Ireland (1995). It would be of interest to re-evaluate the quantitative importance of slowly adjusting beliefs in the context of a better model of money. Exploring the welfare implications of policy credibility within the context of such a model would also be of interest; see Moran (1997) for some preliminary work in this area. Second, our analysis restricts monetary policy to be one of two regimes. Extending the analysis to incorporate the possibility of several regimes would likely result in beliefs that are even slower to adjust to policy changes. Third, a promising extension would be to endogenize monetary policy so as to evaluate the role of strategic interaction between policy makers and the general public in belief formation. Finally, to the extent that the monetary authority is bound by fiscal considerations, one may wish to model a policy regime in terms of the state of fiscal policy, as in Ruge-Murcia (1995). For example, the rate of expansion of the federal debt in Canada rose sharply throughout the first half of the 1980s, following the sharp contraction in monetary policy. If the probability of a transition to a loose-money regime increases (or is perceived to increase) with rapidly expanding government debt, then inflation forecasts may have rationally displayed continued persistence even following the disinflation policy of the early 1980s.

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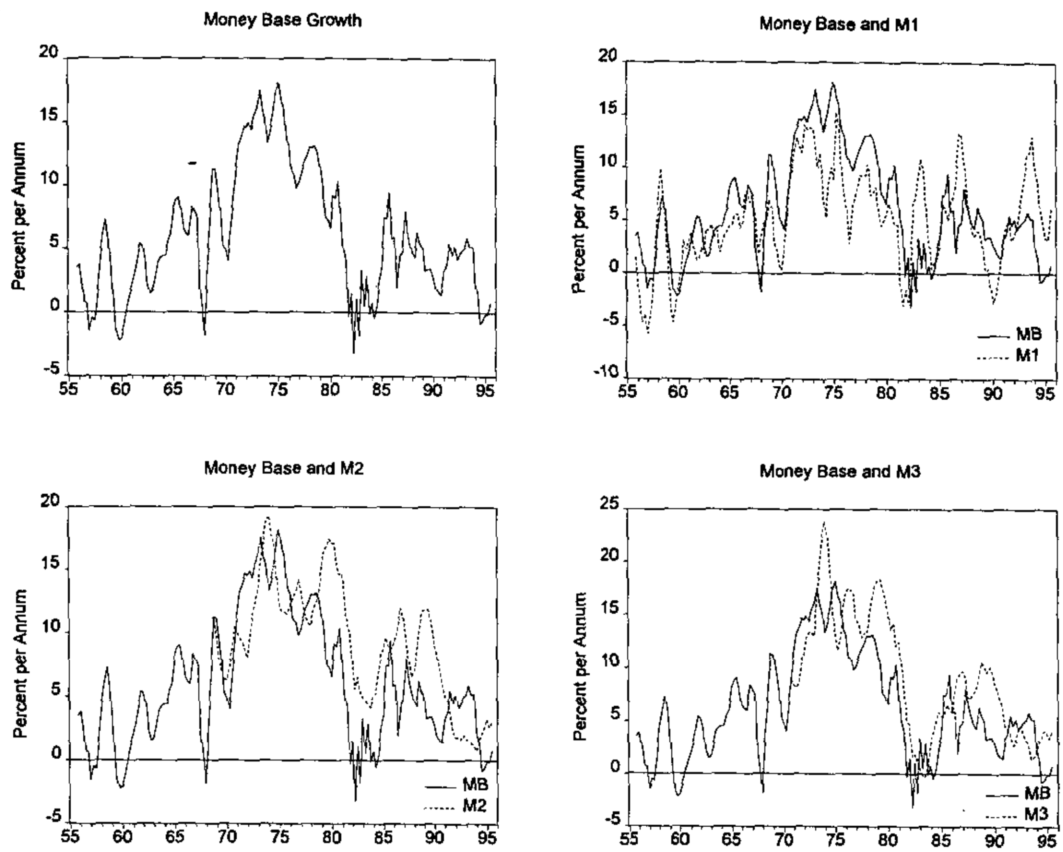
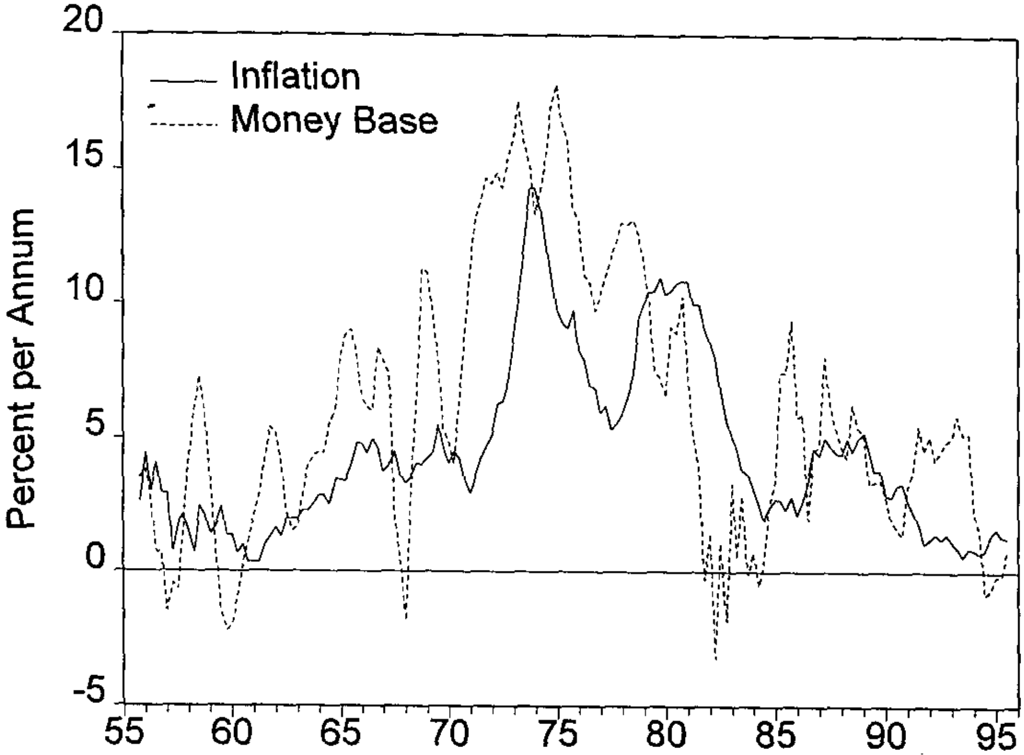
FIGURE 1



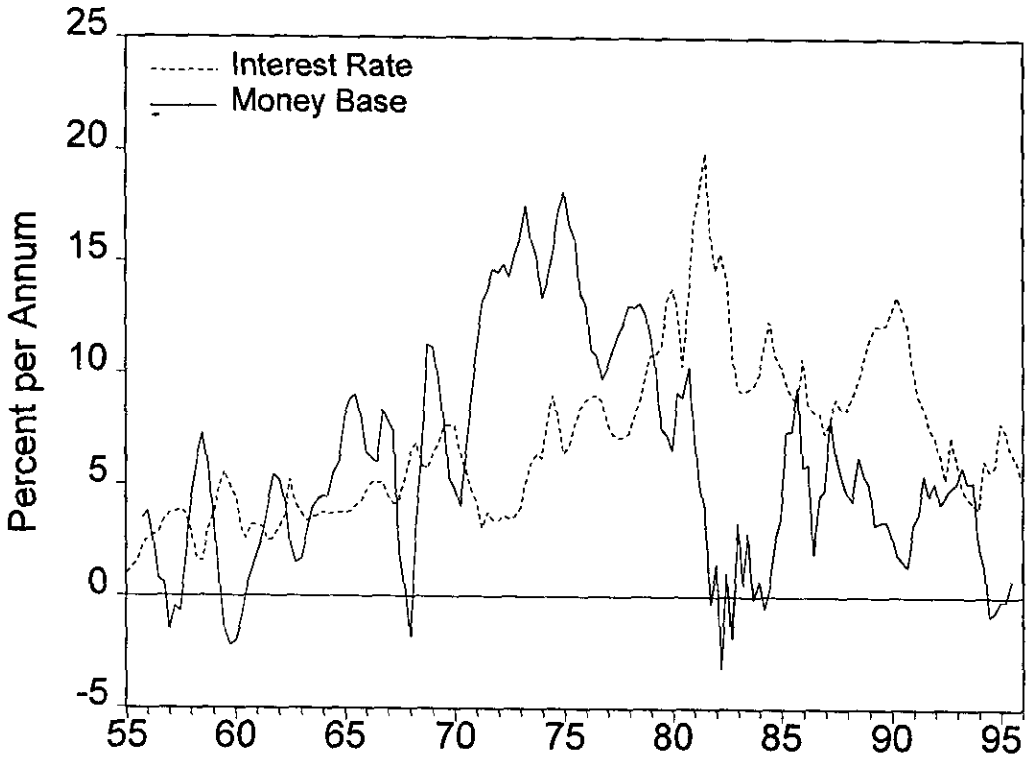
CANSIM Labels: B1646 (Monetary Base); B1627 (M1); B1630 (M2); B1628 (M3); D1 (Population). All monetary aggregates have been deflated by the population; quarterly growth rates have been annualized and smoothed with a five-quarter moving average.

FIGURE 2



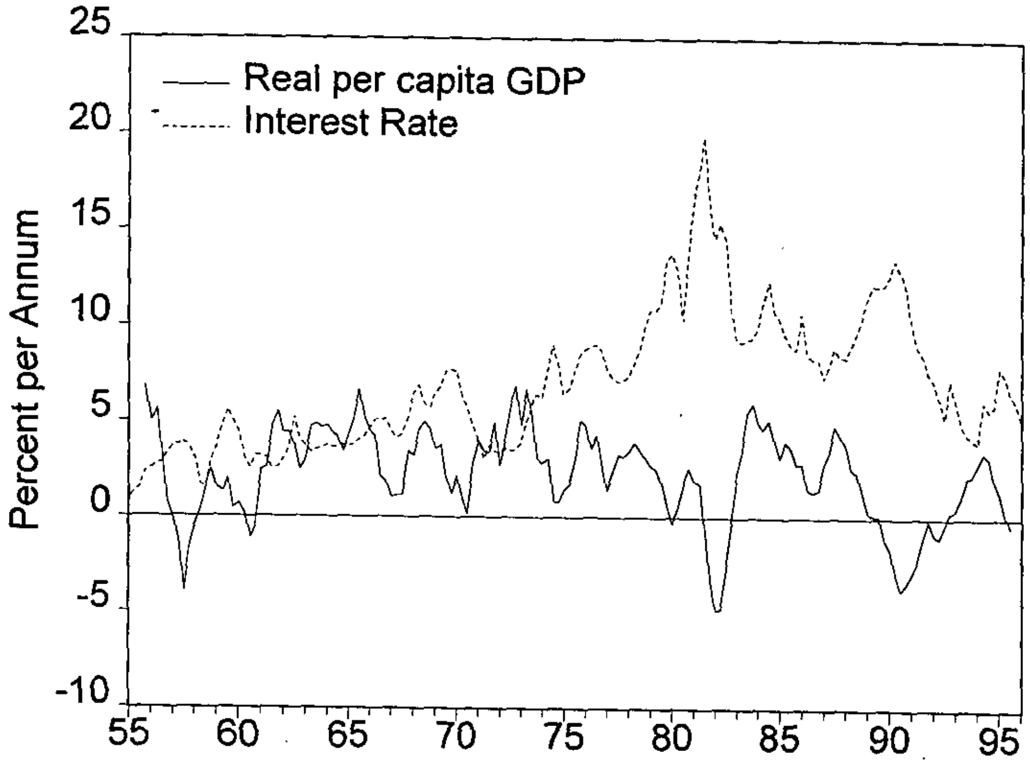
CANSIM Label: D20556 (GDP Deflator). Quarterly rates of change in the price level have been annualized and smoothed with a five-quarter moving average.

FIGURE 3



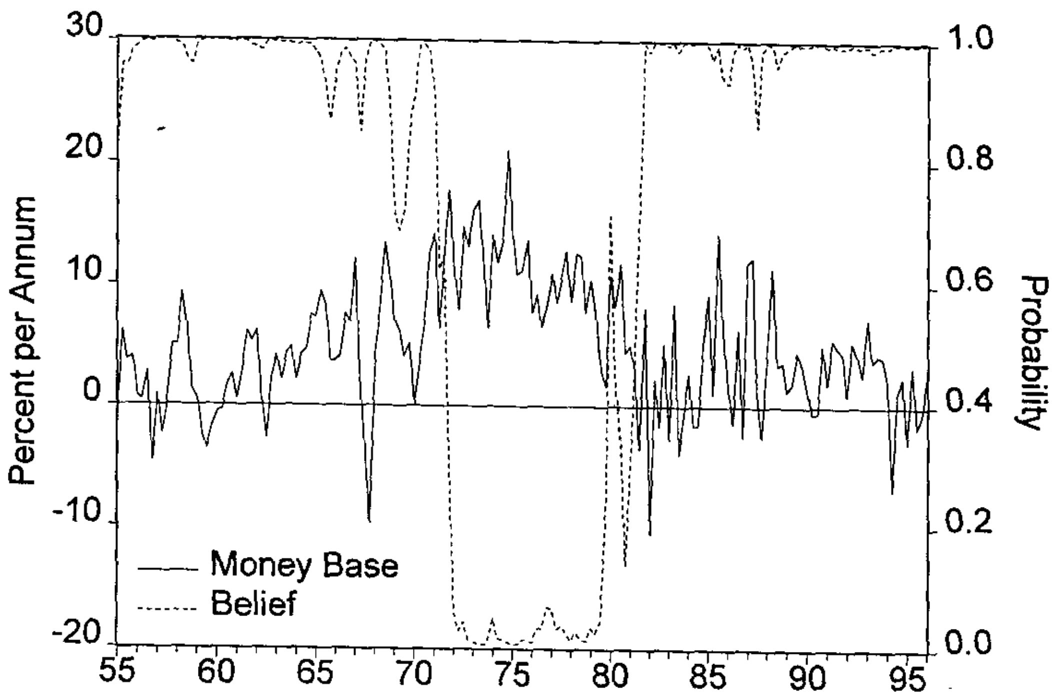
CANSIM Label: B14001 (91 Day Government Treasury Bill Rate, Annualized).

FIGURE 4



CANSIM Label: D20463 (Real GDP). The output measure has been deflated by the population; quarterly growth rates have been annualized and smoothed with a five-quarter moving average.

FIGURE 5



The growth rate in the monetary base is as described in Figure 1 (without smoothing). The initial belief was set to its unconditional mean.

FIGURE 6
Transitory Money Shock

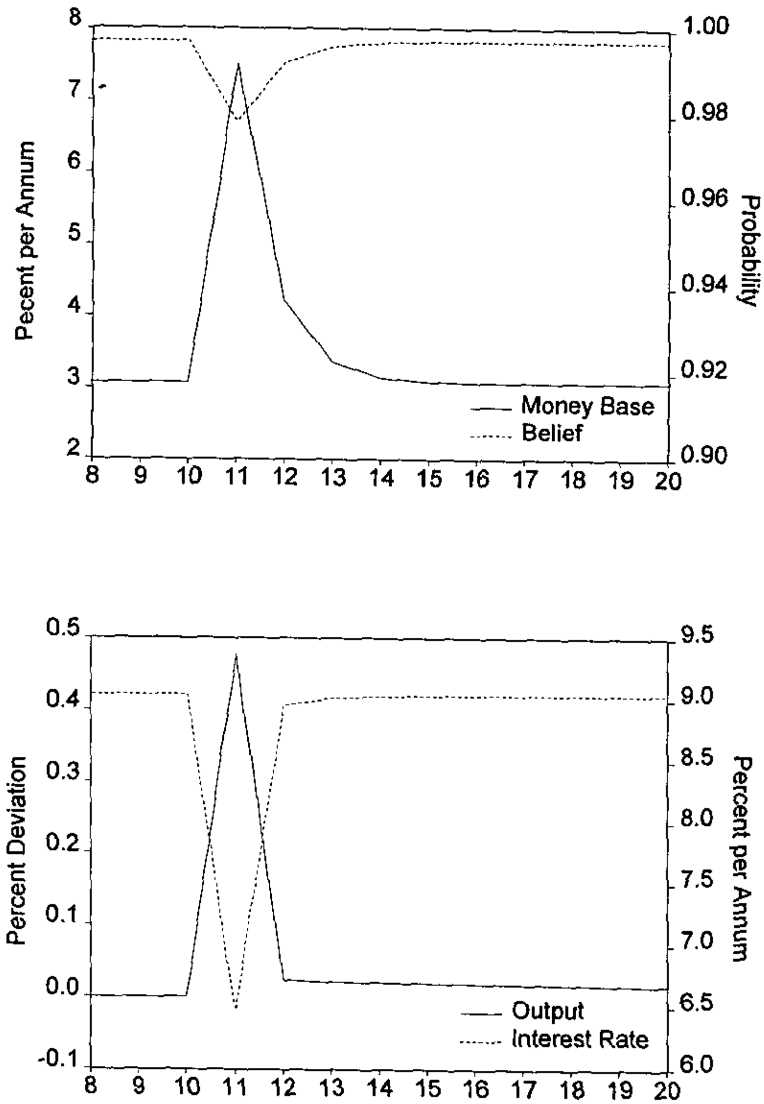


FIGURE 7
Disinflation Policy

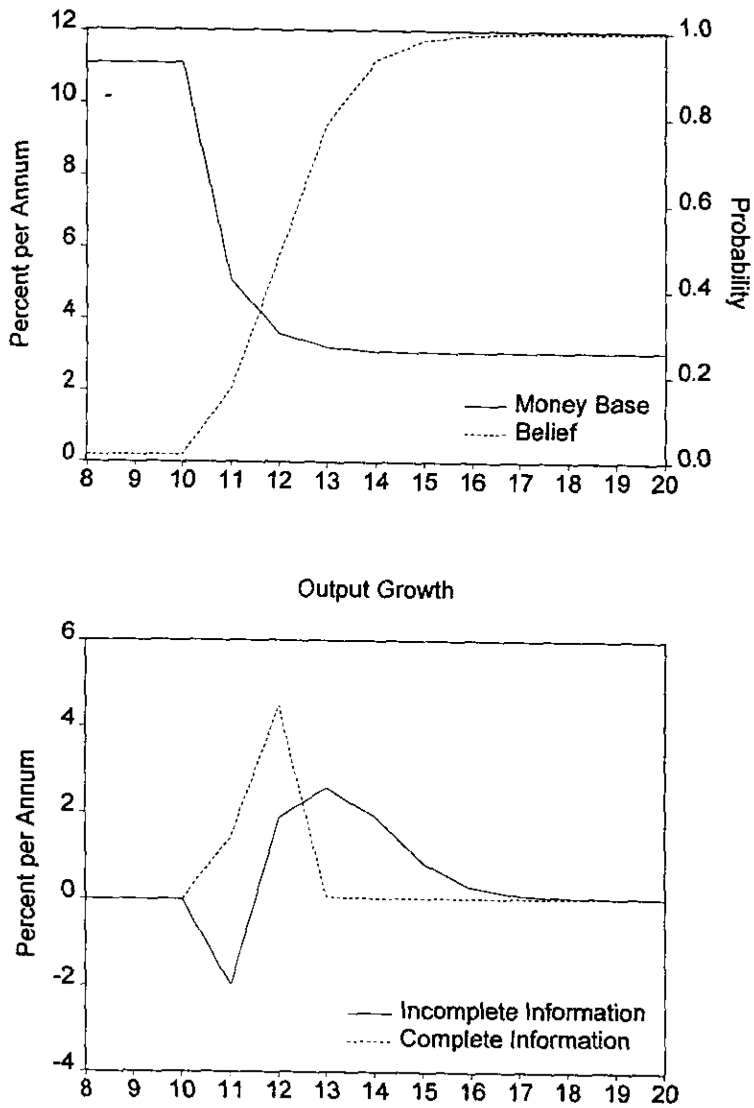
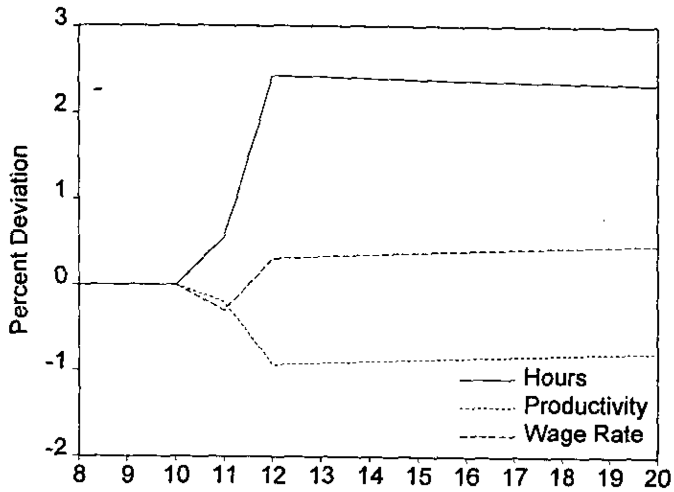


FIGURE 8
Disinflation Policy

Complete Information



Incomplete Information

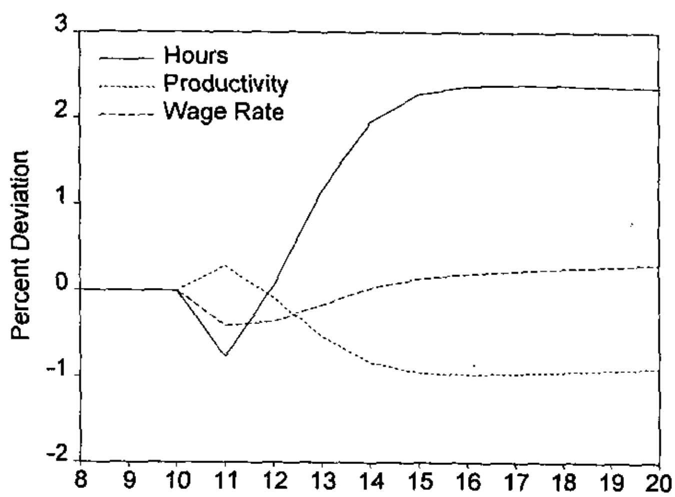
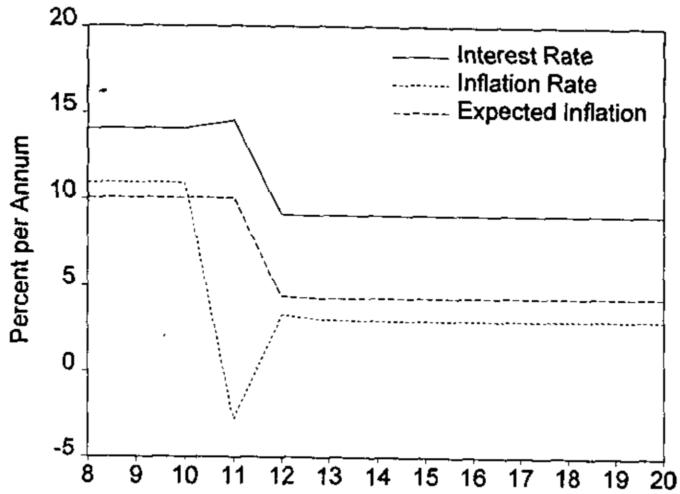


FIGURE 9
Disinflation Policy

Complete Information



Incomplete Information

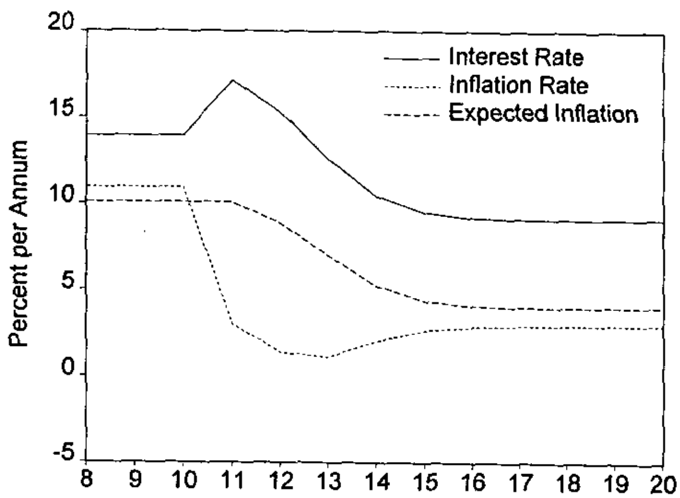
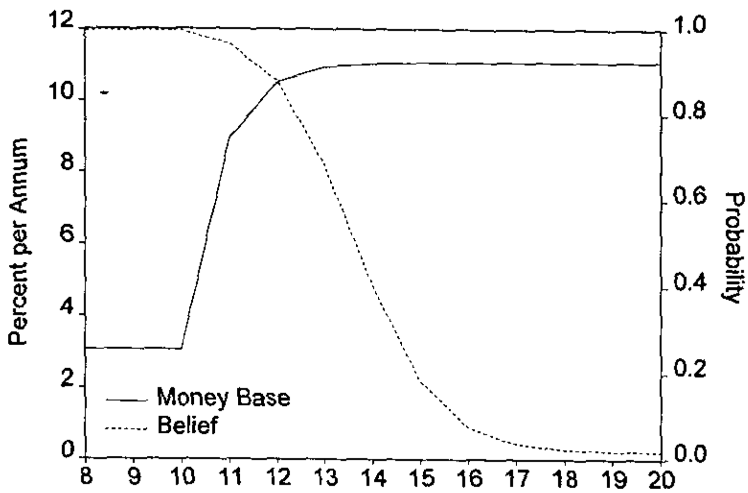


FIGURE 10
Inflation Policy



Output Growth

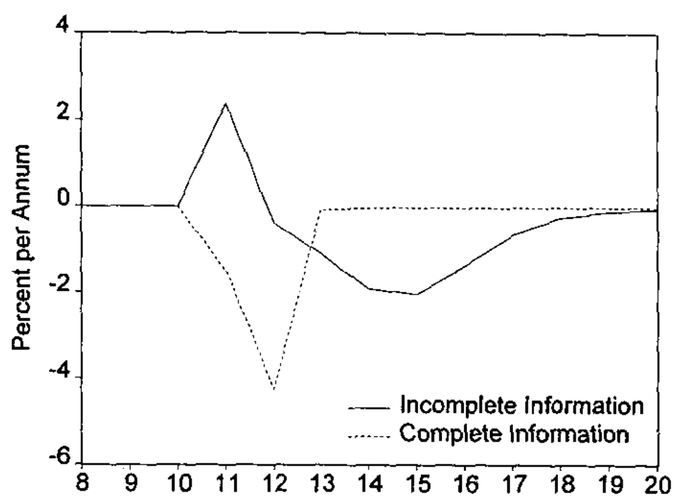
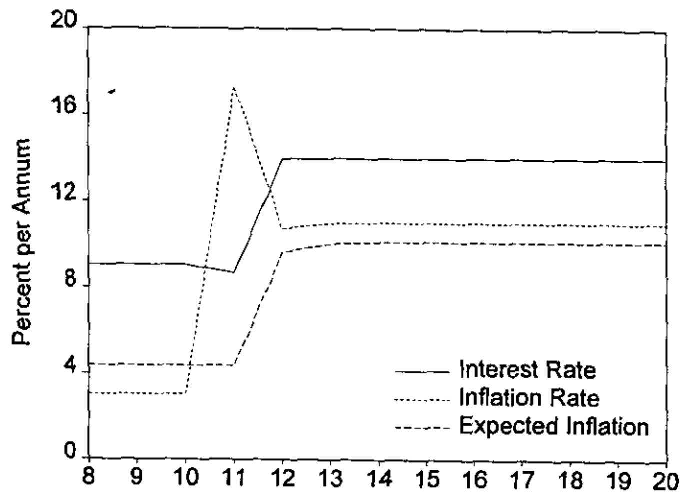


FIGURE 11
Inflation Policy

Complete Information



Incomplete Information

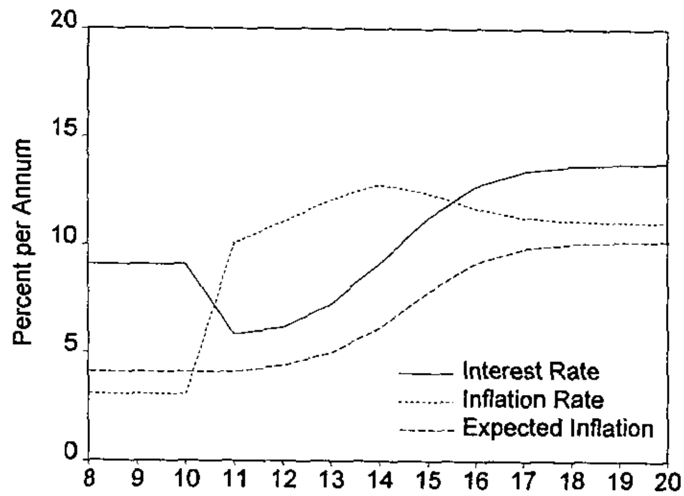


FIGURE 12
Actual Regime Change in 1979:4

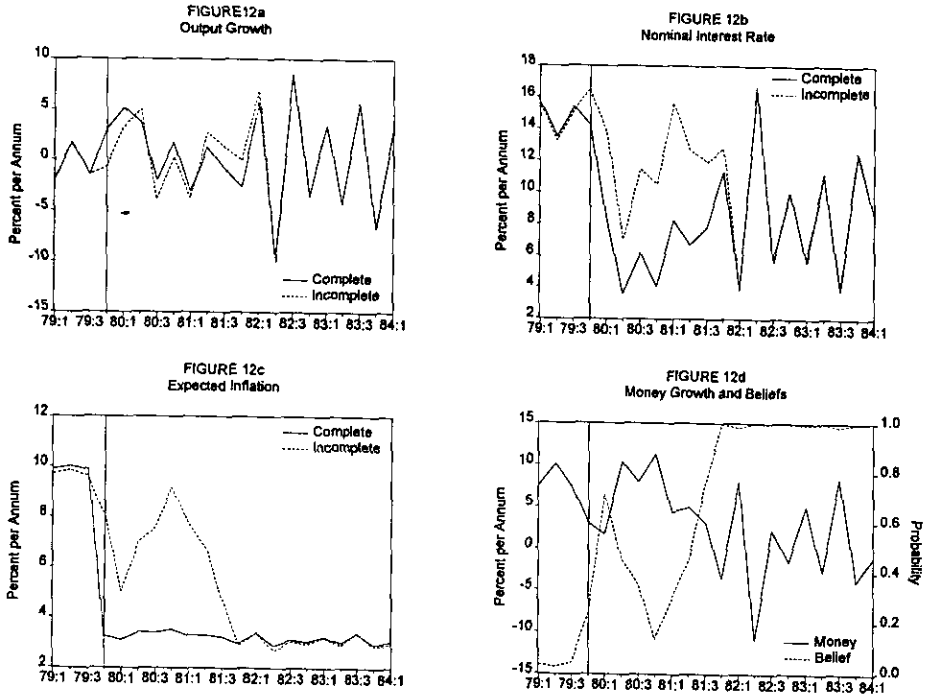


FIGURE 13
Actual Regime Change in 1981:1

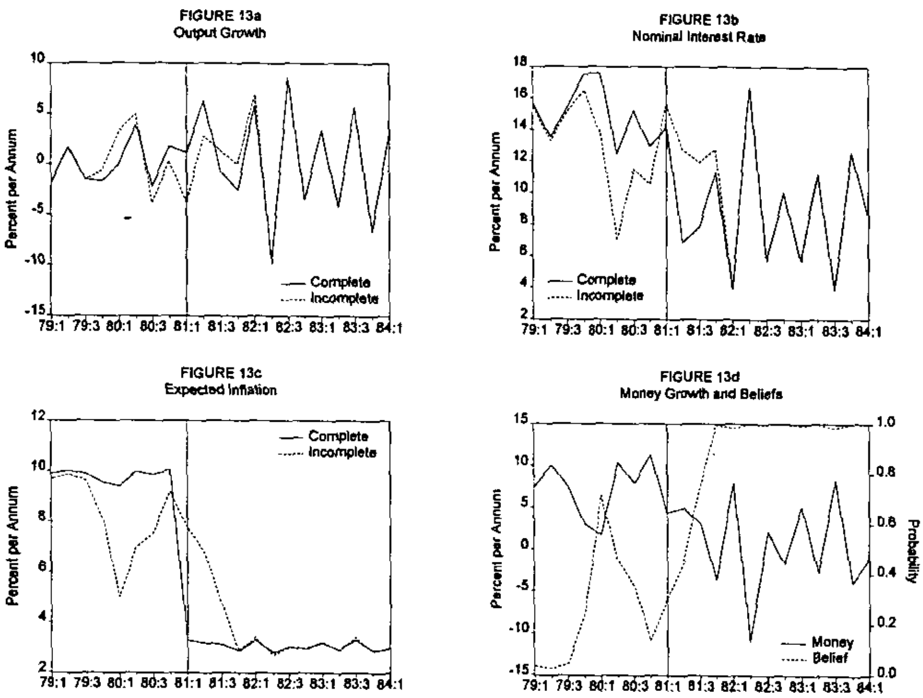


FIGURE 14

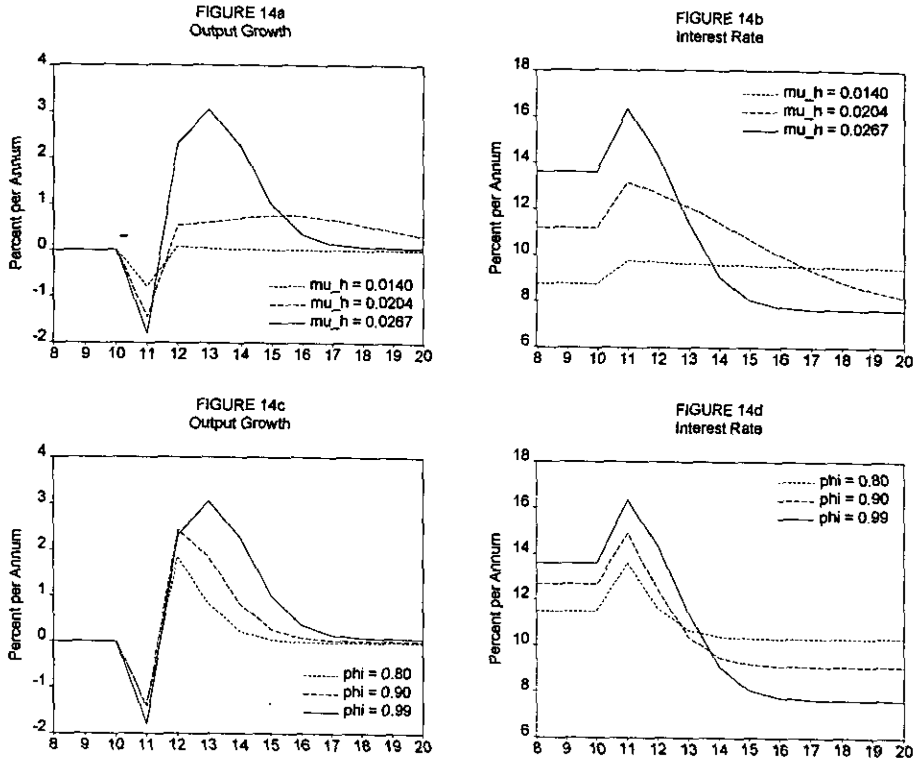


FIGURE 14a
Output Growth
Percent per Annum
mu_h = 0.0140
mu_h = 0.0204
mu_h = 0.0267
FIGURE 14b
Interest Rate
Percent per Annum
mu_h = 0.0140
mu_h = 0.0204
mu_h = 0.0267
FIGURE 14c
Output Growth
Percent per Annum
phi = 0.80
phi = 0.90
phi = 0.99
FIGURE 14d
Interest Rate
Percent per Annum
phi = 0.80
phi = 0.90
phi = 0.99

FIGURE 15

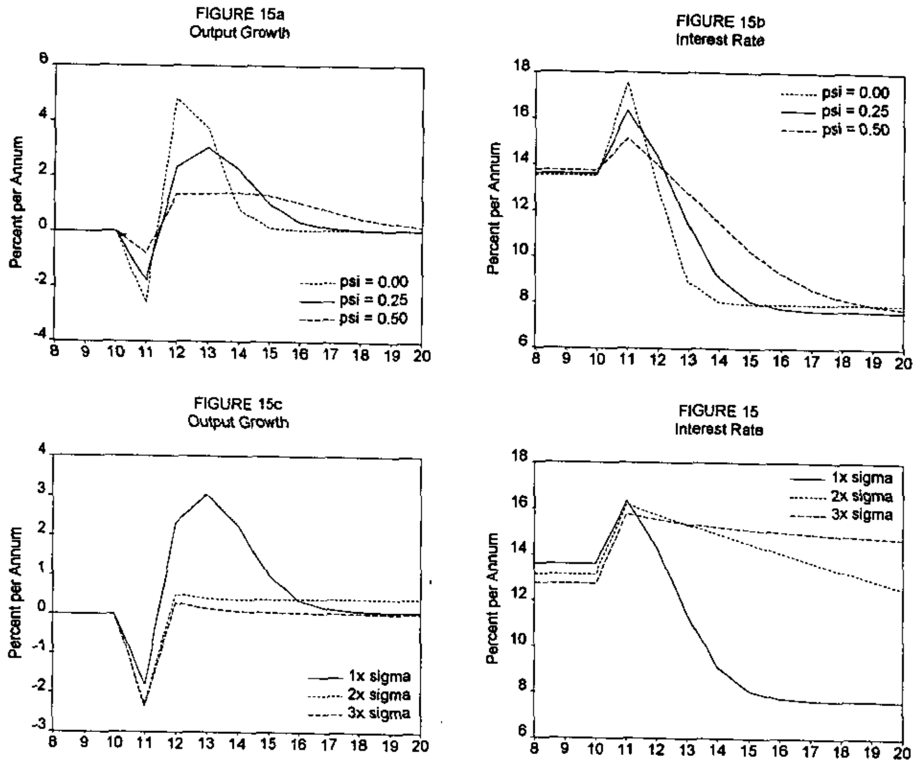


FIGURE 15a
Output Growth
Percent per Annum
psi = 0.00
psi = 0.25
psi = 0.50
FIGURE 15b
Interest Rate
Percent per Annum
psi = 0.00
psi = 0.25
psi = 0.50
FIGURE 15c
Output Growth
Percent per Annum
1x sigma
2x sigma
3x sigma
FIGURE 15
Interest Rate
Percent per Annum
1x sigma
2x sigma
3x sigma

Appendix: Solving for Equilibrium

A.1. Households

Let S_t denote the economy-wide state vector (to be specified shortly), so that (M_t^c, M_t^d, S_t) is the individual state vector for a representative household. Let $V(M^c, M^d, S)$ be the maximum utility obtainable by an optimizing individual in state (M^c, M^d, S); the function V must satisfy the following recursive relationship:

$$
\begin{aligned}
V(M_t^c, M_t^d, S_t) \;=\; & \max_{C_t, N_t, M_{t+1}^c, M_{t+1}^d} \{U(C_t, 1-N_t) + \beta E_t V(M_{t+1}^c, M_{t+1}^d, S_{t+1}) \\
& + \lambda_{1t}\left[W_t N_t + (1+R_t)M_t^d + D_t^f + D_t^b - M_{t+1}^c - M_{t+1}^d\right] \\
& + \lambda_{2t}\left[M_t^c - P_t C_t\right]\}
\end{aligned}
$$

where $C_t, N_t, M_t^c, M_t^d \geq 0$ for all t. Assuming an interior solution, the first-order necessary conditions are given by:

$$
\begin{aligned}
U_1(t) &= P_t \lambda_{2t} \\
U_2(t) &= W_t \lambda_{1t} \\
\beta E_t V_1(t+1) &= \lambda_{1t} \\
\beta E_t V_2(t+1) &= \lambda_{1t}.
\end{aligned}
$$

By the envelope theorem,

$$
\begin{aligned}
V_1(t) &= \lambda_{2t} \\
V_2(t) &= (1+R_t)\lambda_{1t}.
\end{aligned}
$$

Eliminating the multipliers $(\lambda_{1t}, \lambda_{2t})$, one may derive

$$
\frac{U_2(t)}{W_t} = \beta E_t \left\{ \frac{U_1(t+1)}{P_{t+1}} \right\} \tag{A.1}
$$

$$\frac{U_2(t)}{W_t} = \beta E_t \left\{ (1 + R_{t+1}) \frac{U_2(t+1)}{W_{t+1}} \right\}. \tag{A.2}$$

Condition (A.1) governs the accumulation of cash balances. The left-hand side measures the cost associated with earning an extra dollar at date t (working a little more at the nominal wage W_t) while the right-hand side represents the expected benefit of having an extra dollar available at date $t+1$ (spending that dollar on consumption). Condition (A.2) governs the accumulation of deposits. Again, the left-hand side is the utility value of one more dollar at date t. If this dollar is deposited, rather than held as cash, then the individual earns $(1 + R_{t+1})$ dollars in the subsequent period, which are valued at the margin by the (discounted) expected utility value of money at date $t+1$. With cash balances determined, consumption spending is constrained by the cash-in-advance constraint

$$P_t C_t = M_t^c. \tag{A.3}$$

A.2 Goods-Producing Firms

The representative goods-producing firm begins the period with capital stock K_t. Let $J(K_t, S_t)$ denote the maximum expected value of the firm in state (K_t, S_t); this value function must satisfy

$$\begin{aligned} J(K_t, S_t) \;\; = \;\; & \max_{H_t, K_{t+1}} \{ \frac{U_2(t)}{W_t} [P_t F(K_t, H_t) - P_t K_{t+1} - P_t(1-\delta)K_t - (1+R_t)W_t H_t] \\ & + \beta E_t J(K_{t+1}, S_{t+1}) \}, \end{aligned}$$

where we have exploited condition (A.1) to substitute out for the discount factor $\beta E_t U_1(t+1)/P_{t+1}$. Optimal decisions for the firm are characterized by the following first-order conditions:

$$P_t F_2(t) = (1 + R_t) W_t \tag{A.4}$$

$$\frac{P_t U_2(t)}{W_t} = \beta E_t J_1(t+1),$$

with $J_1(t)$ given by the envelope theorem

$$J_1(t) = \frac{P_t U_2(t)}{W_t} \left[F_1(t) + 1 - \delta \right].$$

Combining the relationships above, one may derive

$$\frac{P_t U_2(t)}{W_t} = \beta E_t \left\{ \frac{P_{t+1} U_2(t+1)}{W_{t+1}} \left[F_1(t+1) + 1 - \delta \right] \right\}. \tag{A.5}$$

Condition (A.4) equates the marginal product of labour with the real cost of labour to the firm (which includes its interest rate payments necessary to finance the period labour input). Condition (A.5) governs the accumulation of capital. The left-hand side represents the cost (to shareholders) of a one unit reduction in dividend income, while the right-hand side represents the expected discounted utility value of the extra output generated by a one unit investment in capital goods.

A.3 Market-Clearing Restrictions

Goods, labour, credit and money market-clearing require the following conditions to hold:

$$C_t + K_{t+1} = F(K_t, H_t) + (1 - \delta) K_t \tag{A.6}$$

$$H_t = N_t \tag{A.7}$$

$$M_t^d + X_t = W_t H_t \tag{A.8}$$

$$M_{t+1}^c + M_{t+1}^d = M_{t+1} \tag{A.9}$$

with the money supply/injection evolving according to

$$M_{t+1} = (1 + \mu_t) M_t \text{ or } X_t = \mu_t M_t. \tag{A.10}$$

The restrictions (A.1)–(A.10) jointly characterize a stochastic process

$$\{C_t, N_t, H_t, K_{t+1}, M^c_{t+1}, M^d_{t+1}, M_{t+1}(X_t), P_t, W_t, R_t\}.$$

A.4 Transformation

Since money grows over time, nominal variables must be transformed so as to render them stationary. To this end, deflate all nominal variables by the period money stock and denote such deflated variables with lowercase as follows:

$$m^c_t \equiv \frac{M^c_t}{M_t}, \quad m^d_t \equiv \frac{M^d_t}{M_t}, \quad p_t \equiv \frac{P_t}{M_t}, \quad w_t \equiv \frac{W_t}{M_t}, \quad x_t \equiv \frac{X_t}{M_t}.$$

Using the labour market clearing condition (A.7) to eliminate H_t, the system of equations may now be written as:

$$p_t c_t = m^c_t \tag{A.11}$$

$$(1+\mu_t)\frac{U_2(t)}{w_t} = \beta E_t\left\{\frac{U_1(t+1)}{p_{t+1}}\right\} \tag{A.12}$$

$$(1+\mu_t)\frac{U_2(t)}{w_t} = \beta E_t\left\{(1+R_{t+1})\frac{U_2(t+1)}{w_{t+1}}\right\} \tag{A.13}$$

$$p_t F_2(t) = (1+R_t)w_t \tag{A.14}$$

$$\frac{p_t U_2(t)}{w_t} = \beta E_t\left\{\frac{p_{t+1}U_2(t+1)}{w_{t+1}}\left[F_1(t+1)+1-\delta\right]\right\} \tag{A.15}$$

$$1+\mu_t = w_t N_t + m^c_t \tag{A.16}$$

$$C_t + K_{t+1} = F(K_t, H_t) + (1-\delta)K_t \tag{A.17}$$

where the restrictions $m_t^c + m_t^d = 1$ and $x_t = \mu_t$ have been employed above. The system (A.11)–(A.17) now characterize a stationary stochastic process

$$\{C_t, N_t, K_{t+1}, R_t, p_t, w_t, m_t^c\}.$$

A.5 The Aggregate State Vector

The economy-wide state vector for both the complete and incomplete information model is given by the 4-tuple $S_t = (K_t, m_t^c, \mu_t, b_t)$, where recall that b_t represents the probability that individuals attach to the tight-money regime *after* observing the current money growth realization μ_t. Under complete information, b_t is equal to either zero or unity depending on which regime is actually in place. Under incomplete information, b_t varies continuously between zero and unity, depending on observed money growth rates and the Bayesian updating formula.

In presenting the model and the associated equilibrium restrictions, no explicit distinction was made between the complete and incomplete information environments. In effect, the expectations operator hides this distinction. In the complete information case, individuals must concern themselves with both the possibility of a regime change and the distribution of the monetary control error (under each regime). Thus, the conditional expectation of a random variable $z_{t+1} = z(\epsilon_{t+1})$ is given by

$$E_t\left[z_{t+1} \mid i\right] = \sum_{j\in\{L,H\}} \int \phi_{ij} f_j(\epsilon_{t+1}) z(\epsilon_{t+1}) d\epsilon_{t+1}, \quad i \in \{L, H\}.$$

Under incomplete information, the expectation of z_{t+1} is conditioned on a current belief b_t that generally lies between zero and unity;

$$E_t\left[z_{t+1} \mid b_t\right] = \sum_{j\in\{L,H\}} \left[b_t \int \phi_{Lj} f_j(\epsilon_{t+1}) z(\epsilon_{t+1}) d\epsilon_{t+1} + (1-b_t) \int \phi_{Hj} f_j(\epsilon_{t+1}) z(\epsilon_{t+1}) d\epsilon_{t+1}\right]$$

for $b_t \in [0, 1]$.

A.6 Solution Method

Equilibrium decision rules and pricing functions are obtained computationally by applying an Euler equation iteration technique developed by Coleman (1991). Equations (A.1)–(A.17) represent a system of nonlinear second-order difference equations. Coleman's algorithm reduces this system to a set of first-order difference equations by conjecturing candidate decision rules and pricing functions, and interpolating these functions when evaluating the expectations in (A.12), (A.13) and (A.15). The decision rules and pricing functions are then updated by solving the set of nonlinear first-order difference equations. The algorithm iterates on these decision rules and pricing functions, terminating when two successive solutions are deemed sufficiently similar. The expectations in (A.12), (A.13) and (A.15) are evaluated numerically, a procedure known as quadrature.