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**Monetary Policy Regimes
and Beliefs**

by David Andolfatto and Paul Gomme



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Monetary Policy Regimes and Beliefs*

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Abstract: This paper investigates the role of beliefs over monetary policy in propagating the effects of monetary policy shocks within the context of a dynamic, stochastic general equilibrium model. In our model, monetary policy periodically switches between low and high money growth regimes. When individuals are unable to observe the regime directly, they will have to form inferences over regime-type based on historical money growth rates. We show that for an empirically plausible money growth process, beliefs evolve slowly in the wake of a regime change. As a result, our model is able to capture some of the observed persistence of real and nominal variables following such a regime change.

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1 Introduction

This paper is motivated by the following three observations. First, in many countries, monetary policy can be described roughly as having fluctuated between ‘loose-money’ and ‘tight-money’ regimes. These policy regimes manifest themselves as prolonged periods of alternately high and low inflation; see [Ricketts and Rose \(1995\)](#). Second, an identifiable change in monetary policy appears to induce a persistent ‘liquidity effect.’ [Romer and Romer \(1989\)](#), for example, find that episodes of contractionary monetary policy are characterized by prolonged periods of relatively high interest rates and depressed economic activity. Third, expectations of inflation appear to evolve sluggishly relative to inflation and money growth in the wake of a policy change; see [Dotsey and DeVaro \(1995\)](#). Furthermore, inflation expectations at times appear to be ‘biased’ in the sense of under- or over-predicting inflation for long periods of time; see [Thomas \(1999\)](#).

The purpose of this paper is to develop a dynamic general equilibrium model capable of accounting for these observations. We assess the extent to which the theory might be used to interpret Canadian data. From Figures 1–4, we see that the Canadian experience is generally consistent with the observations reported above. Figure 1 displays the growth rates for base money and the broader money aggregates. From the mid-1950s through to the early 1970s, base money growth averaged around 3 1/4% per annum. The 1970s were characterized by a more rapid expansion of base money, with growth rates averaging around 10% per annum. Since the early 1980s, base money has again averaged around 3 1/4% per annum. The broader monetary aggregates display a similar behavior. Figure 2 demonstrates how base money growth and inflation exhibit similar secular trends. Figures 3 and 4 provide evidence for the liquidity effect. In particular, notice how the rapid expansion of base money during the early 1970s is associated with a falling interest rate. Likewise, the sharp decline in base money growth during the late 1970s and early 1980s is associated with a rising interest rate. Figure 4 demonstrates how rising interest rates are typically associated with falling GDP growth rates. Finally, notice how the interest rate appears to lag money growth. To the extent that the interest rate embeds within it an expectation of inflation, this behavior suggests that inflation expectations appear to behave ‘adaptively,’ especially in the wake of significant changes in the persistent component of money growth.

Standard theory has a difficult time in accounting for the behavior of output and interest rates following an exogenous monetary policy shock; see [Christiano \(1991\)](#). The ‘limited participation’ models of [Lucas \(1990\)](#) and [Fuerst \(1992\)](#) are capable of generating a liquidity effect, but one which displays almost no persistence. [Christiano and Eichenbaum \(1992\)](#) and [Cooley and Quadrini \(1999\)](#), however, demonstrate how an *ad hoc* portfolio adjustment cost can generate persistence. [Cook \(1999\)](#) is also able to generate persistence by assuming that financial intermediation costs depend on some lagged measure of aggregate economic activity. None of these environments are able to account for sluggishly evolving inflation expectations.

In this paper, we hypothesize that the joint behavior of output, interest rates and inflation expectations might, in part, be attributable to the regime-switching nature of monetary policy. We do not ask *why* monetary policy is subject to regime shifts.¹ Instead, we wish to explore the implications for macroeconomic activity *given* the regime-switching nature of monetary policy. The crucial assumption we make is that the true monetary policy regime is not observable by private sector agents, and that the central bank cannot make credible announcements concerning

¹One possible explanation is provided by [Christiano and Gust \(2000\)](#).

regime-type. Consequently, if money growth varies for reasons other than regime changes, the private sector will have to form *beliefs* concerning the true nature of the prevailing monetary policy regime. These beliefs will presumably be formed rationally and will be updated on the basis of all available information (in particular, the historical realizations of actual money growth); as in [Cukierman and Meltzer \(1986\)](#), individuals will be faced with a signal-extraction problem. In such an environment, beliefs (and hence inflation forecasts) will evolve slowly relative to actual money growth rates and actual inflation. Furthermore, it is possible for inflation forecasts to remain above or below actual inflation rates for very long periods of time. At the same time, the sluggish expectation formation induces an endogenous sluggishness in the household portfolio decision, an effect that may contribute to the persistence of the liquidity effect following a regime change. The purpose of our paper is to investigate the extent to which the belief-formation mechanism described above can deliver a pattern of post-shock dynamics that are broadly consistent with the evidence.

Our results can be summarized as follows. First, when we apply [Hamilton's \(1989\)](#) Markov regime-switching estimator to Canadian base money growth, we find evidence of two distinct money-growth regimes: a tight-money regime, with average money growth equal to 3% per annum; and a loose-money regime, with average money growth equal to 6.5% per annum. Actual regime changes are estimated to be infrequent events, with regimes lasting on average around 10 years. As discussed in [Subsection 4.4](#), other sample periods yield estimates of the high money growth rate closer to 11%, and an average duration of the low money growth regime of around 30 years.

Second, conditional on this parameterization of monetary policy, we find that the 'credibility' of a monetary policy change (i.e., whether or not individuals know the true nature of monetary policy) can have important implications for the way a model economy adjusts to a change in monetary regime. In particular, without credibility, a disinflation policy may first induce recession and a prolonged period of 'above normal' interest rates. In addition, rational inflation forecasts can exceed actual inflation for long periods of time. A credible disinflation policy, on the other hand, induces a much quicker transition to a regime of lower interest rates and higher output.

Third, when applying the model to Canada's disinflation episode over the late 1970s and 1980s, we find that the noncredibility of policy may have had quantitatively important effects. Under our baseline parameterization, we find that an actual regime change in the fourth quarter of 1979 (from loose money to tight money) resulted in interest rates and inflation expectations that were on average two percentage points higher throughout the 1980s than they would otherwise have been if the disinflation policy was fully credible. Noncredibility is estimated to have cost the economy one-half percent of GDP in each year of that decade.

The paper proceeds as follows. The economic environment is described in [Section 2](#). In [Section 3](#), the stochastic process governing the evolution of base money is estimated and the model is calibrated. The key results of the paper are reported in [Section 4](#), which analyzes the behavior of the model economy following a monetary policy regime change. [Section 5](#) briefly reports the welfare benefit of a disinflation policy under different information structures. In [Section 6](#), we consider a particular episode in Canadian monetary history: the disinflation of the early 1980s. [Section 7](#) concludes.

2 Model

2.1 Households

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

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

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 labor (N_t) and leisure;

$$(2) \quad N_t + L_t = 1.$$

The allocation of the household's money balances is determined at the end of the previous period; this allocation decision will be described shortly.² A portion of these money balances, M_t^d , is committed to 'deposits' at the financial intermediary. These funds earn a return $R_t > 0$ with the principal and interest being paid at the end of period t .

The remainder of the household's funds are held in the form of 'transactions cash,' M_t^c , and are available to make current-period purchases. More specifically, each household is composed of a worker-shopper pair. At the start of the period, the pair separate with the shopper taking the household's cash to the output market while the worker visits the labor market in order to generate labor income. The shopper's purchases of consumption goods are constrained by the household's transactions cash; i.e.,

$$(3) \quad M_t^c \geq P_t C_t$$

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.³ Thus, end-of-period money income is given by

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

²Alternative formulations of the limited participation model allow households to divide their money holdings between 'cash' and 'deposits' at the beginning of the period, but before the realization of the money growth shock. For practical purposes, these different formulations are equivalent.

³We assume, without loss, that shares in business sector equity are not traded.

and money balances evolve according to:

$$(4) \quad M_{t+1}^c + M_{t+1}^d = Y_t + M_t^d + (M_t^c - P_t C_t).$$

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)–(4), 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.

Notice that the portfolio allocation decision made at the end of period t is made in reference to the *future* division of money between transactions cash and deposits (recall that M_t^c and M_t^d are predetermined as of date t). In particular, the household cannot condition its portfolio decision on any future monetary policy shock, but rather must make this choice on the basis of its expectation of future monetary policy. To the extent that expectations display any stickiness, so too will the portfolio decision. It is this effect that will serve to propagate the liquidity effect.

The Euler equations associated with household maximization are:

$$(5) \quad \frac{U_2(C_t, L_t)}{W_t} = \beta E_t \left\{ \frac{U_1(C_{t+1}, L_{t+1})}{P_{t+1}} \right\}$$

and

$$(6) \quad \frac{U_2(C_t, L_t)}{W_t} = \beta E_t \left\{ (1 + R_{t+1}) \frac{U_2(C_{t+1}, L_{t+1})}{W_{t+1}} \right\}.$$

Condition (5) 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 (6) governs the accumulation of deposits. Again, the left-hand side is the utility value of acquiring one more dollar at date t . If this dollar is deposited, rather than held as cash, then the individual has $(1 + R_{t+1})$ dollars in the subsequent period, which are valued at the margin by the (discounted) expected utility value of money at date $t + 1$.

2.2 Firms

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

$$(7) \quad 0 \leq Q_t \leq F(K_t, H_t),$$

where $F(K, H) = K^\theta H^{1-\theta}$. The capital stock is owned by the firm, but labor 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. Cash earnings do not arrive in time to finance the period wage bill. After repaying its business loans and paying for its capital expenditures, the firm remits any remaining cash as a dividend payment to households;

$$(8) \quad D_t^f = P_t Q_t - P_t I_t - (1 + R_t) W_t H_t.$$

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

$$(9) \quad K_{t+1} = (1 - \delta) K_t + I_t,$$

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

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

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

subject to (7)–(9), given a stochastic process for $\{P_t, W_t, R_t, \Delta_t | t \geq 0\}$ 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

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

The Euler equations governing the firm's optimization are:

$$(10) \quad P_t F_2(K_t, N_t) = (1 + R_t) W_t$$

and

$$(11) \quad \frac{P_t U_2(C_t, L_t)}{W_t} = \beta E_t \left\{ \frac{P_{t+1} U_2(C_{t+1}, L_{t+1})}{W_{t+1}} [F_1(K_{t+1}, N_{t+1}) + 1 - \delta] \right\}.$$

Condition (10) equates the marginal product of labor with the real cost of labor to the firm (which includes its interest rate payments necessary to finance the period labor input). Condition (11) governs the accumulation of capital.⁴ 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.

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 deposits M_t^d provided by households, is supplied

⁴Note that the consumers' Euler equations have been used in deriving (11).

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

$$(12) \quad \begin{aligned} D_t^b &= (1 + R_t) \left[M_t^d + X_t \right] - (1 + R_t) M_t^d \\ &= (1 + R_t) X_t \end{aligned}$$

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. Money growth evolves according to:

$$(13) \quad \mu_t - \hat{\mu}_t = \psi(\mu_{t-1} - \hat{\mu}_{t-1}) + \varepsilon_t, \quad |\psi| < 1$$

where $\hat{\mu}_t$ is the ‘long-run’ money growth rate at date t and ε_t is a random disturbance (monetary control error) drawn from a Normal distribution function $N(0, \sigma_t^2)$.

A *monetary policy regime* is characterized by a ‘long-run’ rate of monetary expansion $\hat{\mu}_t$, and a standard deviation of the monetary control error, σ_t . For simplicity, it is assumed that there are only two regimes:

$$(\hat{\mu}_t, \sigma_t) \in \{(\mu_L, \sigma_L), (\mu_H, \sigma_H)\}.$$

where $\mu_L < \mu_H$. (There is no presumption that $\sigma_L < \sigma_H$.) Monetary policy regimes switch back and forth over time according to a Markov transition law with known parameters:

$$(14) \quad \phi_{ij} = \Pr[(\hat{\mu}_t, \sigma_t) = (\mu_j, \sigma_j) | (\hat{\mu}_{t-1}, \sigma_{t-1}) = (\mu_i, \sigma_i)] \quad i, j = L, H.$$

Of course, $(\hat{\mu}_t, \sigma_t)$ represents a ‘long-run’ regime only to the extent that ϕ_{LL} and ϕ_{HH} are in some sense ‘close’ to unity.

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

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

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 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 $\Gamma_t = \{\mu_t, \mu_{t-1}, \mu_{t-2}, \dots\}$, together with any prior information.

Let $b_t \equiv \Pr[\hat{\mu}_t = \mu_L | \Gamma_t]$ 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):

$$(15) \quad b_t = \frac{g_L(b_{t-1}, \mu_t)}{g_L(b_{t-1}, \mu_t) + g_H(b_{t-1}, \mu_t)}$$

where

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

where $f_i(\varepsilon)$ for $i \in \{L, H\}$ denotes the density function of the monetary control error in each regime. The function g_L represents the likelihood that the current money growth rate, μ_t , was generated under the tight-money regime, given the prior belief b_{t-1} . The first term is the product of: (1) the probability attached to being in the tight-money regime last period, (2) the probability of no regime transition, and (3) the probability of observing the current money growth rate given no transition. Likewise, the second term is the product of: (1) the probability attached to the loose-money regime being in place last period, (2) the probability of making the transition from the loose-money to the tight-money regime, and (3) the probability of seeing the current money growth rate given this transition. Similarly, g_H is the likelihood that current money growth was generated under the loose-money regime.

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 (15) lie strictly between 0 and 1, an individual will never be absolutely certain as to the central bank's type.

Second, for parameters like those reported below, learning *will* occur. For example, suppose that at time t an agent assigns a high probability to the tight-money regime ($b_t \approx 1$). 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 money growth rates associated with the low money growth regime 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 realized money growth rates that are more likely to have come from the high money growth regime. Thus, individuals may incorrectly infer a change in monetary policy when there has, in fact, been none.

Finally, since a regime is associated with both a money growth rate and a variance of the monetary control error, agents will in general use not only the current *level* of money growth but also its *variability* in forming their beliefs. For example, if individuals place a large likelihood on the ‘tight’ money regime being in place, they may find the current money growth rate ‘unusual’ because it is closer to the mean growth rate of the ‘loose’ money regime and/or because the likelihood that the money control error is drawn from the ‘tight’ money regime is remote.

2.7 Expectations

Thus far, no explicit distinction has been 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 $z_{t+1} = z(\varepsilon_{t+1})$ is given by

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

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

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

for $b_t \in (0, 1)$.

2.8 Competitive Equilibrium

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

$$\{C_t, N_t, L_t, M_{t+1}^c, M_{t+1}^d, Q_t, H_t, I_t, K_{t+1}, D_t^f, D_t^b | t \geq 0\}$$

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

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

which represent the goods, money, loans and labor markets, respectively.

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 labeled the *anticipated inflation effect* (or the Fisher effect) and the *liquidity effect*. Below, we discuss both effects in turn.

Consider an unanticipated, but persistent, reduction in money growth (for example, the implementation of a lower long-run inflation target). Under complete information, individuals rationally lower their inflation forecasts accordingly. Since inflation acts as a tax on labor earnings, the anticipation of lower inflation increases the expected return to working and hence leads to an increase in the supply of labor (for any given real wage). Under incomplete information, inflation expectations initially remain high (relative to the case of complete information) as individuals are unsure as to whether the lower money growth realization represents an actual regime change, or just a transitory deviation from the current regime. In this latter case, the labor supply response will be muted.

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 the interest rate in an attempt to secure the cash loans that they need in order to finance the period labor input. Normally, raising the interest rate would 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, the interest rate rises leading to a fall in labor demand and a decline in output. In this way, the liquidity effect causes employment and output to contract and the interest rate to rise. The liquidity effect on employment works in an opposite direction to the anticipated inflation effect (the period interest rate is determined primarily by the liquidity effect); in equilibrium either effect may dominate depending on the configuration of the model's parameter values.⁵ However, because the anticipated inflation effect is muted in the incomplete information environment, it is more likely that the liquidity effect will dominate in this case.

In the complete information environment, the household's portfolio decision is influenced by the expected future reduction in loanable funds and lower inflation; i.e., there will be a shift away from transactions cash into deposits. For this reason, the liquidity effect will be short-lived. But in

⁵See [Christiano \(1991\)](#) for further details.

the incomplete information environment, the portfolio adjustment displays an endogenous stickiness owing to the persistence in beliefs. Consequently, future deposits – and hence future loanable funds – will be curtailed relative to the complete information case; i.e., households wish to maintain a relatively large supply of transactions cash because they expect inflation to remain high. That is to say, they initially place a large weight on the current low money growth rate being a transitory deviation. The sluggish portfolio response of the household sector means that in the subsequent period, when money growth is once again low (recall that we are assuming that the regime change did in fact occur), financial markets will once more be ‘surprised’ by the unanticipated shortfall in loanable funds even in the absence of any further money shock. These ‘surprises’ will continue as long as beliefs take time to adjust. In this way, the liquidity effect may persist.

2.9 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:

$$m_t^c \equiv \frac{M_t^c}{M_t}, \quad m_t^d \equiv \frac{M_t^d}{M_t}, \quad p_t \equiv \frac{P_t}{M_t}, \quad w_t \equiv \frac{W_t}{M_t}, \quad x_t \equiv \frac{X_t}{M_t}.$$

Using the labor market clearing condition to eliminate H_t , the system of equations may now be written as:

$$(16) \quad p_t C_t = m_t^c$$

$$(17) \quad (1 + \mu_t) \frac{U_2(C_t, 1 - N_t)}{w_t} = \beta E_t \left\{ \frac{U_1(C_{t+1}, 1 - N_{t+1})}{p_{t+1}} \right\}$$

$$(18) \quad (1 + \mu_t) \frac{U_2(C_t, 1 - N_t)}{w_t} = \beta E_t \left\{ (1 + R_{t+1}) \frac{U_2(C_{t+1}, 1 - N_{t+1})}{w_{t+1}} \right\}$$

$$(19) \quad p_t F_2(K_t, N_t) = (1 + R_t) w_t$$

$$(20) \quad \frac{p_t U_2(C_t, 1 - N_t)}{w_t} = \beta E_t \left\{ \frac{p_{t+1} U_2(C_{t+1}, 1 - N_{t+1})}{w_{t+1}} [F_1(K_{t+1}, N_{t+1}) + 1 - \delta] \right\}$$

$$(21) \quad 1 + \mu_t = w_t N_t + m_t^c$$

$$(22) \quad C_t + K_{t+1} = F(K_t, N_t) + (1 - \delta) K_t$$

where the restrictions $m_t^c + m_t^d = 1$ and $x_t = \mu_t$ have been employed above. The system (16)–(22) now characterize a stationary stochastic process $\{C_t, N_t, K_{t+1}, R_t, p_t, w_t, m_t^c\}$.⁶

⁶Equilibrium decision rules and pricing functions are obtained computationally by applying an Euler equation iteration technique developed by [Coleman \(1991\)](#).

3 Calibration

The parameters of the model are given by

$$\begin{aligned} \text{Preferences: } & \beta, \omega, \gamma \\ \text{Technology: } & \theta, \delta \\ \text{Monetary Policy: } & \mu_L, \mu_H, \phi_{LL}, \phi_{HH}, \psi, \sigma_L, \sigma_H. \end{aligned}$$

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 the regime switching model of Hamilton (1989) to data on per capita base-money growth for Canada over the sample period 1955:2–2000:4. 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 behavior of the series.⁷

The actual estimation was undertaken with a GAUSS program written by Hamilton. The parameter estimates are given in Table 1.⁸

Table 1: Parameter Estimates, Sample Period 1955:2–2000:4

<i>Parameter:</i>	μ_L	μ_H	ϕ_{LL}	ϕ_{HH}	ψ	σ_L^2	σ_H^2
<i>Estimate:</i>	0.0074	0.0161	0.9741	0.9780	0.4305	0.00004670	0.00019120
<i>Standard Error:</i>	0.0015	0.0026	0.0246	0.0194	0.0729	0.00001051	0.00002864

The estimation procedure identifies two regimes with the following features. In the ‘tight-money’ regime, money growth averages 0.74% per quarter (3.00% per annum) with a standard deviation of 0.68%, while in the ‘loose-money’ regime, money growth averages 1.61% per quarter (6.50% per annum) with a standard deviation of 1.38%. In other words, a loose-money policy is associated not only with higher money growth, but also more volatile money growth (although, volatility relative to mean is roughly the same across the two regimes). Furthermore, the estimation identifies long-term trends in each regime (as opposed to trends that fluctuate at business cycle frequencies); i.e., the average duration of each regime is roughly ten years $(1 - 0.976)^{-1} \approx 42$ quarters. The autoregressive component of money growth within each regime is estimated to be only moderately persistent (0.43).

Figure 5 depicts the actual money growth series together with the estimated belief that the monetary authority is following the tight-money program at any given date, conditional on all currently available information (i.e., historical money growth rates and the initial belief). The estimation suggests that in the early part of the sample (up until around 1967), individuals were

⁷As in the Kalman filter, the time path of an observed series is used to draw inferences about an unobserved state variable. While the Kalman filter is a linear algorithm for generating estimates of a continuous unobserved state variable, the Hamilton filter is a nonlinear algorithm and provides inferences over an unobserved discrete-valued variable.

⁸The initial belief b_0 was set equal to its unconditional mean: $(1 - \phi_{HH}) / (2 - \phi_{LL} - \phi_{HH})$.

confident that they were operating under a tight-money regime. From 1967-72, there appears to be considerable uncertainty over policy regime in the sense beliefs were fluctuating widely between the two regimes. By 1972, belief in the loose-money regime had become entrenched. While retrospective studies of Canadian monetary policy date the shift back to a low inflation regime to the early 1980s, the estimates in Table 1 suggest that people had difficult time in believing that an actual change in policy had been implemented.⁹ In fact, throughout the entire 1980s, confidence in the tight-money regime fluctuated significantly, never surpassing 30%, in spite of the fact that money growth remained low (relative to the 1970s). The puzzling behavior of beliefs over this period can be rationalized by noting that while money growth tended to be low, it also displayed considerable volatility – a feature that is associated with the loose-money regime. Not until 1990 did the public gain confidence in the tight-money regime; this belief remained fairly stable with brief exceptions during 1994-95 and at the very end of the sample period. These two exceptions reveal two very different ways in which confidence in the tight-money regime may be adversely affected. In the latter part of the sample, we see that relatively high and volatile money growth rates can trigger a change in beliefs. During the 1994-95 sample period (and in other periods as well), we see that money growth is relatively low, a large decline in the money growth rate might signal a change to a *loose-money* regime (since big movements in money growth – in any direction – are more commonly associated with loose-money).

4 Results

At the end of Subsection 2.6, we noted that when individuals form beliefs over the current regime, they will use information not only about the *level* of money but also its *variability* since regimes differ in both their mean growth rate and also the standard deviation of the monetary control error. Consequently, we need to perform stochastic simulations of the model to afford agents the opportunity to use information about the variability of money when they form their beliefs.¹⁰ The impulse-responses presented below are the *averages* taken over 10,000 simulations of the model.

4.1 Transitory Shocks

Figure 6 displays the impulse-response functions for money growth, beliefs, output, and the interest rate following a positive one-standard-deviation shock in the transitory component of money growth in the incomplete information environment and beginning in the tight-money regime. In the impact period of the shock, the interest rate drops over 1 percentage point, while output rises by almost 0.2 percent (relative to its trend under the tight-money regime). Just prior to the shock, belief in the tight-money regime is hovering just over 90%; in the impact period of the expansionary shock, belief in the tight-money regime falls modestly to 85%.

Under the complete information environment (not displayed), the dynamics basically stop here; i.e., the money shock does not propagate. In contrast, the money shock does appear to propagate

⁹As discussed in Subsection 4.4, different sample periods yield parameter estimates that give a different picture of this period. In particular, for a sample period ending 1994:4, beliefs shift back to the low money growth regime by 1982.

¹⁰We are grateful for the comments of an anonymous referee that led us to reconsider how we generated our impulse-responses.

when information is incomplete, although not in the sense that conventional wisdom would dictate. In particular, following the very short-lived economic boom generated by the transitory increase in money growth, the economy enters into a prolonged (if mild) period of recession and relatively high interest rates. What is happening here is that the transitory increase in money growth is partly perceived to be ‘permanent’, owing to the fact that individuals ‘mistakenly’ attach some weight to the possibility that the observed increase in money growth reflects a transition to a loose-money policy.

4.2 A Credible Disinflation Policy

This section considers the economy’s response to a change in monetary policy regime, moving from loose-money to tight-money, in the complete information environment. In the period of the policy change, annual money growth drops from 6.5% to 3.0%. In the impact period of the shock, the interest rates rises a modest 0.6 percentage points, while inflation dropping dramatically by 7.3 percentage points (see Figure 9(a)). Inflation expectations drop immediately in accordance with the new (and known) monetary policy regime. In the second period following the money shock, the interest rate drops to its new ‘long run’ level, while inflation rises to its new ‘long run’ level, both of which are significantly lower than their levels under the previous loose-money regime.

Figure 8(a) records the effect of the change in policy regime on a number of labor market variables. In the impact period of the shock, the unexpected contraction in cash actually causes a moderate economic boom, with employment rising by just over 0.2%. How does one explain the rise in employment in face of the rise in interest rates (which supposedly contracts the demand for labor)? The answer lies in the behavior of labor supply. Recall that inflation expectations drop immediately in the impact period of the shock; leading to a reduction in the anticipated ‘inflation tax’ on labor market earnings and hence results in an increase in the supply of labor at any given wage. In other words, while the demand for labor contracts, the expansion in the supply of labor more than offsets this shift, leading to an expansion in employment (and a drop in real wages). Labor productivity falls in the impact period as employment expands relative to a fixed capital stock.

In the second period following the money shock, employment rises rapidly to its new ‘steady state’ level (about 1.2% above its previous level). This rapid expansion in employment can be attributed to the significant drop in interest rates (and consequent expansion in labor demand) that follow as inflation expectations drop in accordance with the new tight-money regime. Higher labor demand implies higher real wages for workers, but labor productivity actually remains lower than before, reflecting the fact that the capital stock hardly responds at all to the change in policy regime.¹¹

4.3 A Noncredible Disinflation Policy

This section now considers how the economy reacts to the same change in monetary policy regime, but under the assumption of incomplete information; the results are reported in Figures 7, 8(b) and 9(b). As in the experiment considered above, annual money growth drops from 6.5% to 3.0%.

¹¹Note that because firms must borrow cash to finance the labor input, the interest rate drives a wedge between the real wage and labor productivity so that these latter two variables need not move in the same direction.

What are agents thinking upon observing such large decline in money growth? Belief in the loose-money regime is initially high (around 90%). Note that while a 3.5 percentage point drop in money growth is large, it is not inconceivable for people to believe that such a realization is being generated by the relatively volatile loose-money regime. Consequently, belief in the tight-money regime rises only modestly and expectations of inflation fall by only a very small amount. Notice that actual inflation drops significantly in the impact period of the shock, but that the drop is dampened somewhat relative to the complete information environment. With a noncredible disinflation policy, the liquidity effect is now much stronger: the interest rate jumps by almost 1.5 percentage points (more than twice as large as is predicted to occur with a credible disinflation).

In the labor market, the ‘sticky’ inflation expectations imply that there is not much effect on labor supply behavior (workers do not expect any great changes in the inflation tax on their earnings).¹² On the other hand, the demand for labor falls significantly in line with the sudden contraction of liquidity (and higher financing costs). Reduced labor demand results in lower employment and lower real wages, contrary to what is predicted to happen when the disinflation policy is credible.

What is especially interesting to note here is how the signal extraction problem endogenously propagates the effects of the regime change forward in time; i.e., the economy’s dynamic response to the policy change is now much more protracted relative to the complete information environment. To begin, note that the interest rate remains above its initial level even in the period following the shock and subsequently takes several quarters before it closely approaches its new ‘steady state’ level. The transition path for the interest rate mirrors that of inflation expectations, which evolve sluggishly as people only gradually put greater faith in the likelihood of an actual regime change. Furthermore, observe that expectations of inflation appear to be ‘biased’ in the sense of consistently overpredicting actual inflation throughout the transition period; such behavior appears to be consistent with the empirical evidence reported in [Dotsey and DeVaro \(1995\)](#).

The exact mechanism at work here is as follows. The unanticipated shortfall in liquidity is largely interpreted as a transitory ‘monetary control error’ generated by the loose-money regime. Consequently, people do not expect a similar shortfall in liquidity (and correspondingly high interest rate) to recur in the future and so end up keeping ‘too much’ money for transactions purposes and ‘not enough’ money in their interest-bearing saving accounts (where this cash can end up as loanable funds for liquidity strapped firms). Of course, since the tight-money regime is in fact in place, financial markets are once again ‘surprised’ by a shortfall in liquidity (despite the fact that no further shock has occurred). The size of this surprise is smaller in later periods than on impact since beliefs (and hence portfolio decisions) do adjust in the ‘correct’ direction, although in only a small degree (relative to the size of the adjustment that would have taken place if people actually believed the policy change). In this way, a ‘one-time’ regime change can induce a dynamic response similar to what would occur if the economy was hit by a sequence of progressively smaller surprises in money growth.

¹²As pointed out by a referee, including wage income in the household’s cash-in-advance constraint eliminates the unanticipated inflation effect on the labor supply decision. This modification of the cash-in-advance constraint has two other effects. First, the impulse-responses for output look more similar, with a disinflationary policy leading to a recession in both environments. Second, the liquidity effect is generally weaker. Our results should be viewed with this caveat in mind.

4.4 Sensitivity Analysis

Our parameter estimates are sensitive to the sample period used. For samples ending between 1987 and 2000, roughly a quarter have parameter estimates similar to those reported in Table 1. The remaining three-quarters of the samples have parameter estimates similar to those in Table 2 where the sample ends in 1994:4.

Table 2: Parameter Estimates, Sample Period 1955:2–1994:4

<i>Parameter:</i>	μ_L	μ_H	ϕ_{LL}	ϕ_{HH}	ψ	σ_L^2	σ_H^2
<i>Estimate:</i>	0.0082	0.0274	0.9920	0.9633	0.2461	0.00011298	0.00005918
<i>Standard Error:</i>	0.0012	0.0019	0.0088	0.0328	0.0787	0.00001458	0.00001602

There are three important differences between the parameter estimates reported in Table 1 and those in Table 2. First, the growth rate in the ‘loose’ money regime is much higher: around 11% per annum versus 6.5%. Consequently, the difference in the mean growth rates across regimes is much larger, a fact that serves to make it easier for agents to infer that a regime change has taken place. Second, the low money growth regime is associated with the higher standard deviation of the monetary control error; in Table 1, the low money growth regime also had low variability. Finally, the probability of staying in the low money growth regime is higher for the 1994 sample than the 2000 sample. For the 1994 sample, the average duration of the low money growth regime is over 30 years compared with the average duration of 10 years associated with the 2000 sample.

Figure 10 plots Canadian base growth along with the belief generated by using the parameters for the sample ending in 1994. Compared to Figure 5 (parameters for the 2000 sample), individuals continue to attach a high probability to the low money growth regime well into the 1970s. In the 1980s, they are also much quicker to conclude that the low money growth regime is in place. By the end of 1982, they are pretty well convinced that they are dealing with the low money growth regime. This episode will be discussed in greater detail in Section 6.

Qualitatively, the parameter estimates for the sample ending in 1994 generate impulse-responses that are quite similar to those associated with parameters for the 2000 sample. *Quantitatively*, there are three important differences. First, the impact effect of a regime change is substantially larger for the 1994 parameters, since the change in the ‘long run’ growth rate of money is now much larger. A disinflation experiment like that considered in Subsection 4.2 now implies a fall in the annual growth rate of money of 8 percentage points – double that implied by the 2000 parameter estimates. As a result, under incomplete information, the nominal interest rate response is roughly double that presented in Figure 9. The response of other variables is also enhanced, but to a lesser degree.

Second, under incomplete information, it takes individuals much less time to infer that a regime change has taken place. For example, following a disinflation policy, most of the change in beliefs occurs within four quarters of the regime change whereas Figure 7(a) displays a far more protracted adjustment in beliefs.

Third, since the transition probabilities in Table 2 are quite different, the effects of a disinflation are somewhat different from those following an inflationary episode. In particular, the probability of switching from the low to the high money growth regime is less than 1% per quarter compared

with around 4% for the reverse transition. The adjustment in beliefs following a switch from low to high money growth is, then, somewhat more protracted, although not as drawn out as for the 2000 parameter estimates.

Overall, these results highlight the factors that are important for beliefs to adjust sluggishly following a regime change. First, beliefs will adjust quite rapidly if regimes are distinctly different. By way of example, if the monetary control error is fairly small, then the larger is the difference in the mean money growth rates, the easier it is for agents to identify a regime change. Second, when regime changes are infrequent (the probabilities ϕ_{LL} and ϕ_{HH} are close to unity), the belief variable will tend to converge to either zero or one. In this case, it takes longer for beliefs to adjust following a regime change.

5 Welfare Analysis

In this section, we attempt to measure the welfare benefit of implementing a disinflationary policy. To begin, for $\lambda = 0$, we compute the value of living under the loose-money regime as:

$$V^H(\lambda) = \sum_{t=0}^{\infty} \beta^t U(c_t^H + \lambda y_t^H, \ell_t^H)$$

where c_t^H is average consumption, y_t^H is average output, and ℓ_t^H is average leisure under the loose-money regime, where the averages are computed over the 10,000 simulations used for the impulse-responses. The payoff V^H can be computed for both the complete and incomplete information environments.

Next, suppose that the loose-money regime has been in place for a long time, but at date 0 the regime switches permanently to tight-money. The value of this transition is:

$$V^{HL} = \sum_{t=0}^{\infty} \beta^t U(c_t^{HL}, \ell_t^{HL})$$

The superscripts denote a transition from high to low money growth.¹³ For any such realization of money growth, we can compute the welfare benefit as the (unique) value of λ solving

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

The parameter λ represents the fraction of income that an individual living in the high money growth regime would, in retrospect, have been willing to sacrifice for the opportunity of living with the disinflation policy. In the tables below, we compute the average λ across 10,000 simulated regime changes.

Table 3 summarizes the welfare benefit of switching to a tight-money regime (using parameters for the sample ending in 2000). For comparison with the previous literature, the welfare benefit is also calculated ignoring transitional dynamics. There are separate entries for the complete and incomplete information environments since each has slightly different stationary states (under incomplete information, individuals are never quite sure which regime they are in).

¹³The infinite sum is approximated by assuming that after 90 periods the economy has settled into a new stationary state, and assuming that consumption and leisure remain at those levels thereafter.

Table 3: Welfare Benefit of a Disinflation

	<i>Welfare Benefit</i> ($\lambda \times 100$)	
	<i>Complete Information</i>	<i>Incomplete Information</i>
<i>Parameters for Sample Ending 2000:4</i>		
No Transitional Dynamics	0.1128	0.0676
With Transitional Dynamics	0.0398	0.0313
<i>Parameters for Sample Ending 1994:4</i>		
No Transitional Dynamics	0.2461	0.1833
With Transitional Dynamics	0.0678	0.0452

To begin, notice that the welfare figures computed across ‘long-run’ states are in the neighborhood of those reported in the literature (e.g., [Cooley and Hansen, 1989](#)); i.e., around 0.1% of income (in perpetuity) for the 3.5 percentage point fall in inflation (from 6.5% to 3%). Accounting for the transitional path has a significant impact on the measured welfare benefit of disinflation. For both the complete or incomplete information cases, ignoring transitional effects overstates the welfare benefit by over a factor of two. Using the parameter estimates for the sample ending in 1994 gives a fairly similar picture; see [Table 3](#). Ignoring the transitional effects, the welfare costs are comparable to those in the literature. Including the transition path reduces these costs by roughly a factor of 4. 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. There are two effects at work. First, there is a difference in the stationary states associated with either high or low money growth since under incomplete information individuals are never certain which regime they are dealing with. Second, in the incomplete information environment, individuals take a while to figure out that a regime-switch has occurred. Consequently, they continue to act for some time as if a relatively high inflation tax is still in place, thus delaying their adjustment to the new regime.

6 Canada’s Disinflation Episode

Through the mid- to late-1970s and early-1980s, the Bank of Canada declared its intention to reduce inflation. In 1975, the Bank of Canada adopted a policy of “Gradualism” under which it announced growth rate targets for M1. The middle of the target range was gradually reduced in an effort to control inflation. This policy was largely a failure as inflation rose again in the late 1970s; see [Figure 2](#). In retrospect, it appears that the Bank of Canada switched to a tight-money regime sometime in the late-1970s or early-1980s. By 1985, inflation had fallen from double digits to around 3% per annum, and has been fairly stable since then. However, this policy change has also been credited with contributing to the depth and length of the 1981–82 recession, as well as the high interest rates that have prevailed throughout the 1980s.

In this paper, we have identified one mechanism by which a noncredible disinflation could

contribute to below-normal output levels and above-normal interest rates for an extended period of time. Based on our parameter estimates for the sample period ending 2000:4, it would seem that individuals did not believe that the Bank of Canada had in fact switched to a low money growth regime until the late 1980s; see the belief series plotted in Figure 5. 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 experiment considered 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 both the complete and incomplete information environments.¹⁴ Any discrepancy that exists between the predictions of these two versions of the model is then interpreted as an estimate of the quantitative impact of noncredibility.

As regime-type is not observable, the predictions of the model under the complete information environment must be conditioned on the date at which monetary policy is assumed to have switched. Below, we report results assuming that the switch to tight-money occurred in 1979:4. We have experimented with alternative dating of this regime switch, and have found that the qualitative nature of the results are not sensitive to the specific date of the regime switch.

Figure 11 plots the predicted path for output, the interest rate, expected inflation, and beliefs, together with the actual base money growth rate realizations of the Canadian economy over the period 1978:1–90:1, for both complete and incomplete information environments. Judging from these figures, it appears that the noncredibility of policy had a significant impact on the behavior of the economy. Had the disinflation policy in 1979:4 been credible, on average inflation forecasts would have been 3.35 percentage points lower, and interest rates would have been 5 percentage points lower. Furthermore, our results suggest that over this entire decade, real output was depressed by approximately half a percent due to the noncredibility of the Bank of Canada.

Using the parameter estimates for the sample ending in 1994 leads to a somewhat different interpretation of events in Canada through the 1980s; see Figure 12. By mid-1981, beliefs have switched over to the low money growth regime, although there are subsequent quarters when there are substantial drops in beliefs. Under this parameterization, the contribution of monetary policy noncredibility is confined to the two year period between mid-1979 and mid-1981. Over this period, noncredibility is found to have lowered the level of output by an average of 0.8%.

The discussion in Subsection 4.4 provide some insight into why our interpretation of Canadian monetary policy in the 1980s differs so much depending on which set of parameter values we use. From either Figure 5 or Figure 10, it can be seen that money growth was quite volatile through the 1980s. The high money growth rate is higher for the 1994 sample period compared to the 2000 sample (compare Tables 1 and 2). As well, for the 1994 sample, it is the high money growth regime that is associated with low monetary control errors. For the 1994 sample parameters, the lower and more volatile money growth rates in the 1980s are more likely to have been generated by the low money growth regime. Consequently, beliefs rapidly converge to the low money growth regime.

Now, consider the parameter estimates for the 2000 sample. The lower average money growth rates in the 1980s would tend to move beliefs towards the low money growth regime. However, the greater volatility is more likely to have occurred under the high money growth regime. Further, the

¹⁴Given that the model abstracts from all other types of shocks, predicted behavior is perhaps better interpreted as a deviation from what would have happened in the absence of money shocks.

difference in the mean money growth rates across regimes is smaller for this parameterization. The net result is that beliefs switch away from the high money growth regime only late in the 1980s.

7 Conclusion

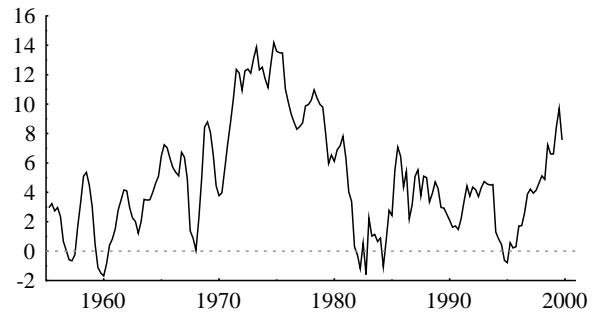
This paper has examined the properties of a dynamic general equilibrium model that features stochastic shifts in monetary policy regimes under alternative information structures reflecting two extreme views on policy credibility. For empirically plausible parameter values describing the structure of the economy, it was demonstrated how the implementation of a credible disinflation policy resulted in a rapid expansion of output together with lower rates of interest. In contrast, a noncredible disinflation policy resulted in a short-lived recession together with persistently higher rates of interest. In this latter case, inflation expectations were shown to evolve sluggishly, with (rational) inflation forecasts persistently exceeding actual inflation along the transition path.

Conditional on our parameterization of the data generating process for monetary policy, we estimated that the change in monetary policy that seemed to occur in Canada some time in the late 1970s or early 1980s took a long time (virtually a decade) before it was firmly believed to have happened by the general public. Confidence in the tight-money regime seems to have been repressed owing to the volatile nature of money growth over the 1980s (a property that appears to be more likely associated with loose-money policies). We calculate that expectations of inflation (and nominal interest rates) would have averaged two percentage points lower – and the level of real output half a percent higher – throughout most of the 1980s had the disinflation policy been fully credible. These conclusions are based on the parameter estimates for the sample ending in 2000:4. For the 1994 sample period parameters, individuals infer that monetary policy switched to low money growth much earlier, and consequently noncredibility of monetary policy is confined to the early 1980s.

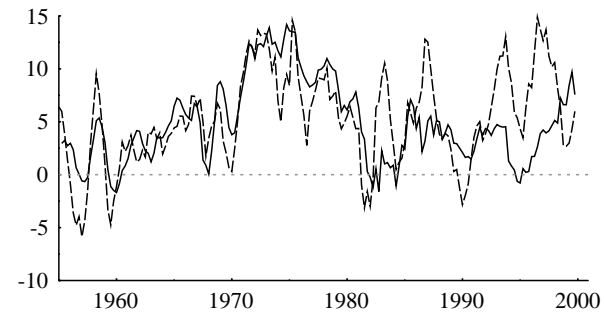
The main point of this paper is that uncertainty over monetary policy regimes can propagate the liquidity effect associate with exogenous regime changes. While the analysis above contains more than its fair share of abstraction, none of this is likely to significantly affect the main message of the paper, although obviously details and quantitative implications might differ. One criticism that has been leveled at the framework here concerns the specification of monetary policy; i.e., in the model, money growth is completely exogenous while in reality it seems to respond to the state of the economy. This observation is likely more relevant for what we have termed ‘monetary control errors’ and one could easily imagine embedding a policy reaction function around each of the exogenous regimes. As far as modeling the regimes themselves, we believe that it is appropriate to treat these as exogenous, since they are likely determined by forces that are beyond the scope of most conventional economic models, like fiscal shocks or changes in the central bank’s objective function.

References

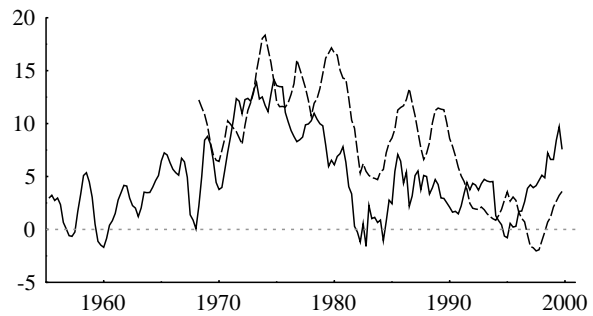
- CHRISTIANO, L. J., "Modeling the Liquidity Effect of a Money Shock," *Federal Reserve Bank of Minneapolis Quarterly Review* 3–34.
- CHRISTIANO, L. J. AND M. EICHENBAUM, "Liquidity Effects and the Monetary Transmission Mechanism," *American Economic Review* 82 (1992), 346–353.
- CHRISTIANO, L. J. AND C. GUST, "The Expectations Trap Hypothesis," in K. Clinton and W. Engert, (eds.) "Money, Monetary Policy, and Transmission Mechanisms," (Ottawa, Canada: Bank of Canada) (2000) 347–383.
- COLEMAN, W. J., II, "Equilibrium in a Production Economy with an Income Tax," *Econometrica* 59 (1991), 1091.
- COOK, D., "The Liquidity Effect and Money Demand," *Journal of Monetary Economics* 43 (1999), 377–390.
- COOLEY, T. F. AND G. D. HANSEN, "The Inflation Tax in a Real Business Cycle Model," *American Economic Review* 79 (1989), 733–48.
- COOLEY, T. F. AND V. QUADRINI, "A Neoclassical Model of the Phillips Curve Relation," *Journal of Monetary Economics* 44 (1999), 165–193.
- CUKIERMAN, A. AND A. H. MELTZER, "A Theory of Ambiguity, Credibility, and Inflation Under Discretion and Asymmetric Information," *Econometrica* 54 (1986), 1099–1128.
- DOTSEY, M. AND J. L. DEVARO, "Was the Disinflation of the Early 1980s Anticipated?" *Federal Reserve Bank of Richmond Economic Quarterly* 81 (1995), 41–59.
- FUERST, T. S., "Liquidity, Loanable Funds, and Real Activity," *Journal of Monetary Economics* 29 (1992), 3–24.
- HAMILTON, J. D., "A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle," *Econometrica* 57 (1989), 357–84.
- LUCAS, R. E., JR., "Liquidity and Interest Rates," *Journal of Economic Theory* 50 (1990), 237–264.
- PRESCOTT, E. C., "Theory Ahead of Business Cycle Measurement," *Federal Reserve Bank of Minneapolis Quarterly Review* 10 (1986), 9–22.
- RICKETTS, N. AND D. ROSE, "Inflation, Learning and Monetary Policy Regimes in the G-7 Countries," Working Paper 95–6, Bank of Canada (1995).
- ROMER, C. D. AND D. H. ROMER, "Does Monetary Policy Matter? A New Test in the Spirit of Friedman and Schwartz," in O. J. Blanchard and S. Fischer, (eds.) "NBER Macroeconomics Annual," (Cambridge, Mass. and London: MIT Press) (1989) 121–170.
- THOMAS, L. B., JR., "Survey Measures of Expected U.S. Inflation," *Journal of Economic Perspectives* 13 (1999), 125–144.



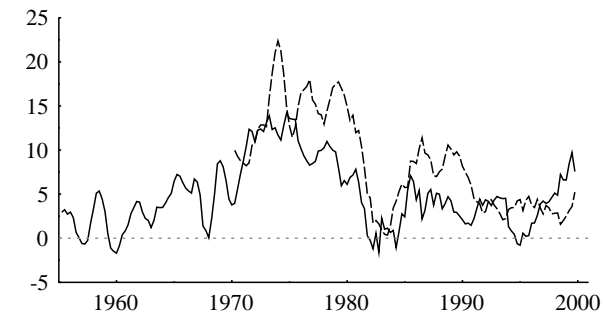
(a) Money Base Growth



(b) Money Base (solid) and M1 (dashed)



(c) Money Base (solid) and M2 (dashed)



(d) Money Base (solid) and M3 (dashed)

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.

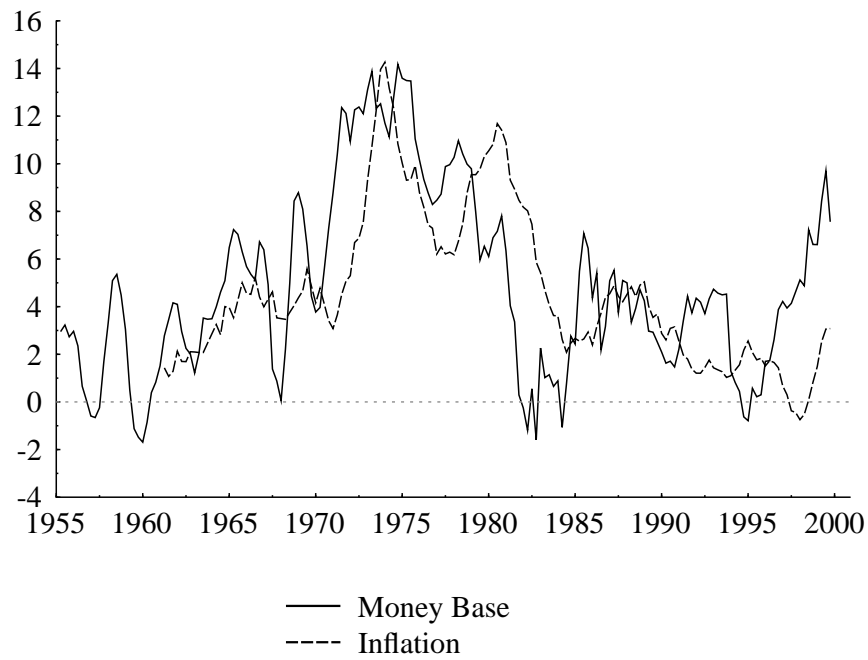


Figure 2: CANSIM Label: D15612 (GDP Deflator). Quarterly rates of change in the price level have been annualized and smoothed with a five-quarter moving average.

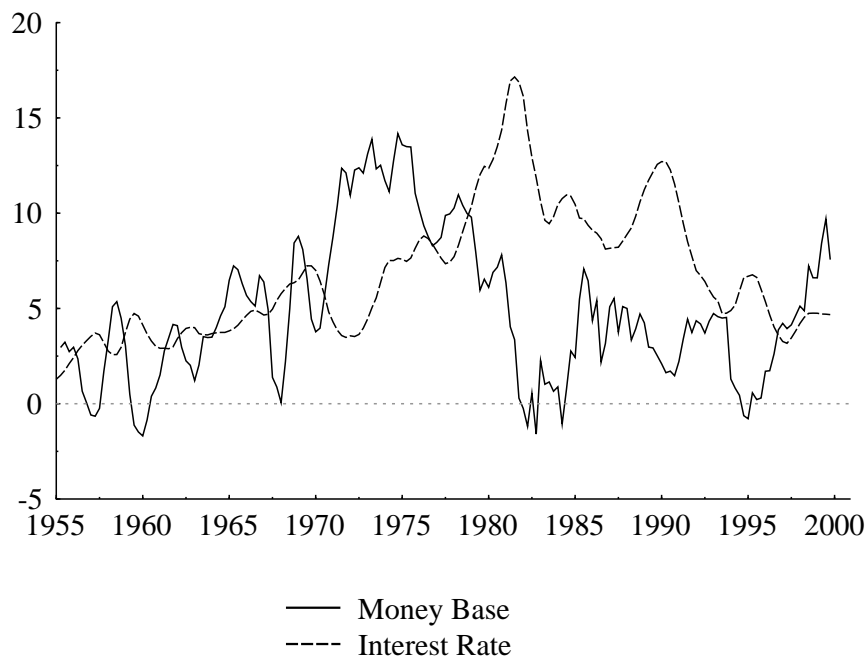


Figure 3: CANSIM Label: B14001 (91 Day Government Treasury Bill Rate, Annualized).

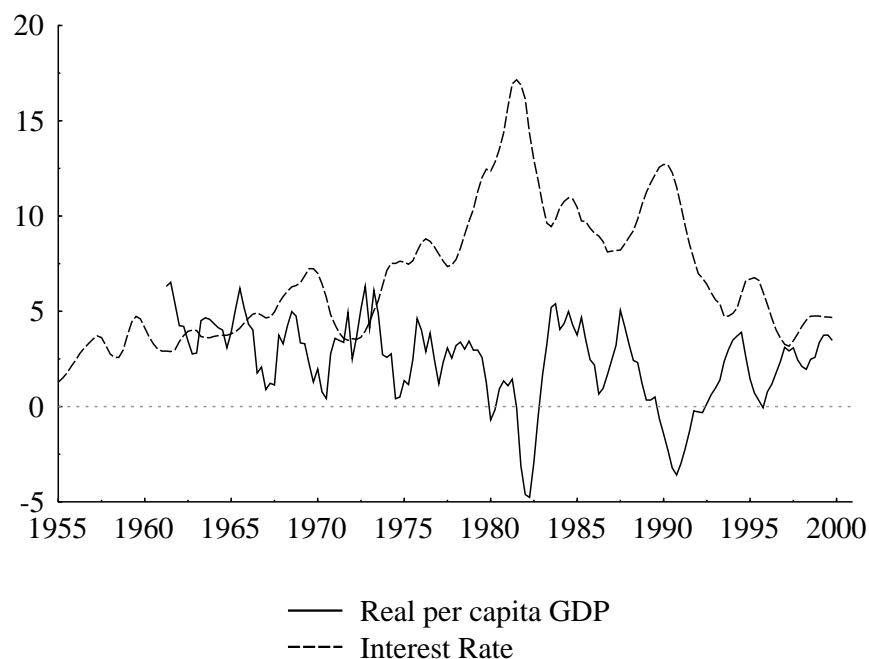


Figure 4: CANSIM Label: D14872 (Real GDP). The output measure has been deflated by the population; quarterly growth rates have been annualized and smoothed with a five-quarter moving average.

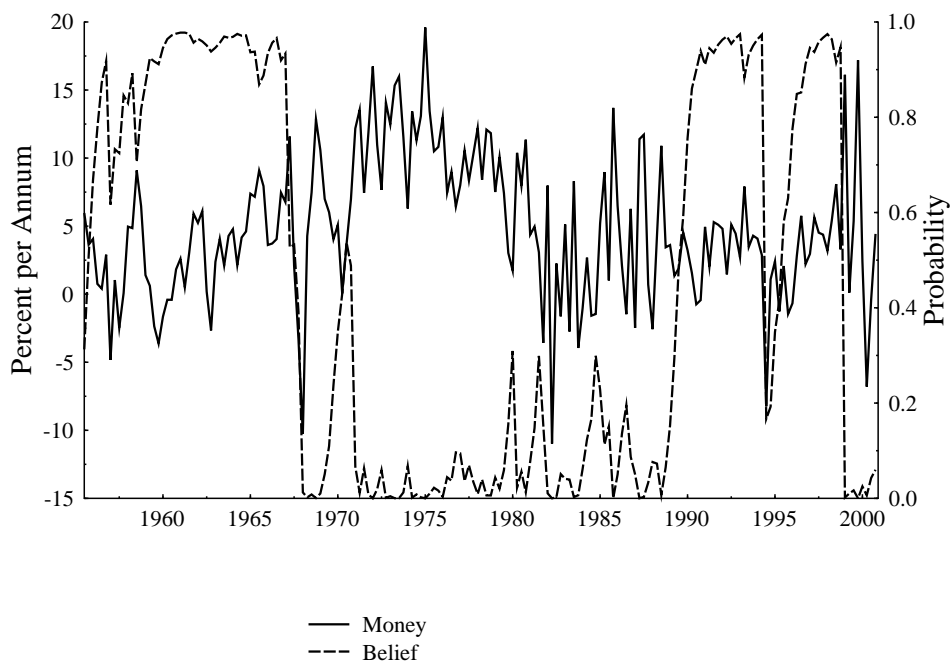
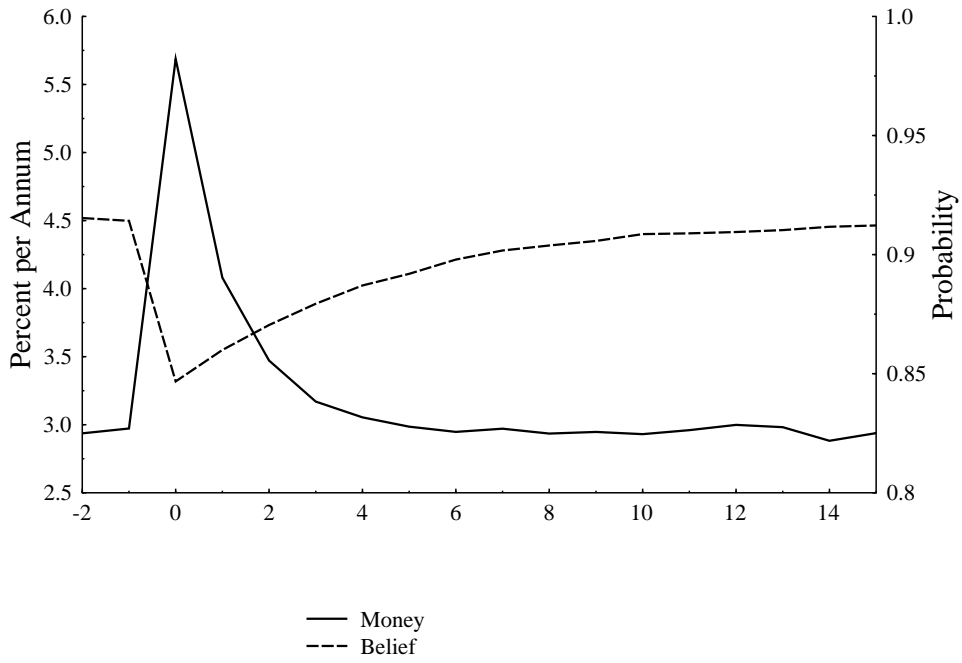
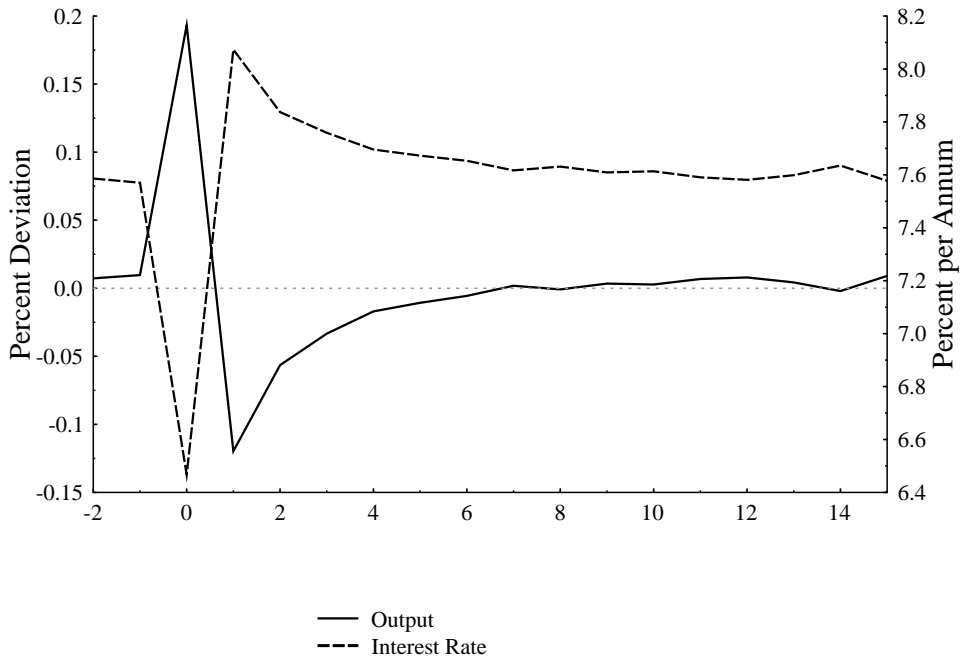


Figure 5: The growth rate in the monetary base is as described in Figure 1 (without smoothing). The initial belief was set to its unconditional mean.

Figure 6: Transitory Money Shock

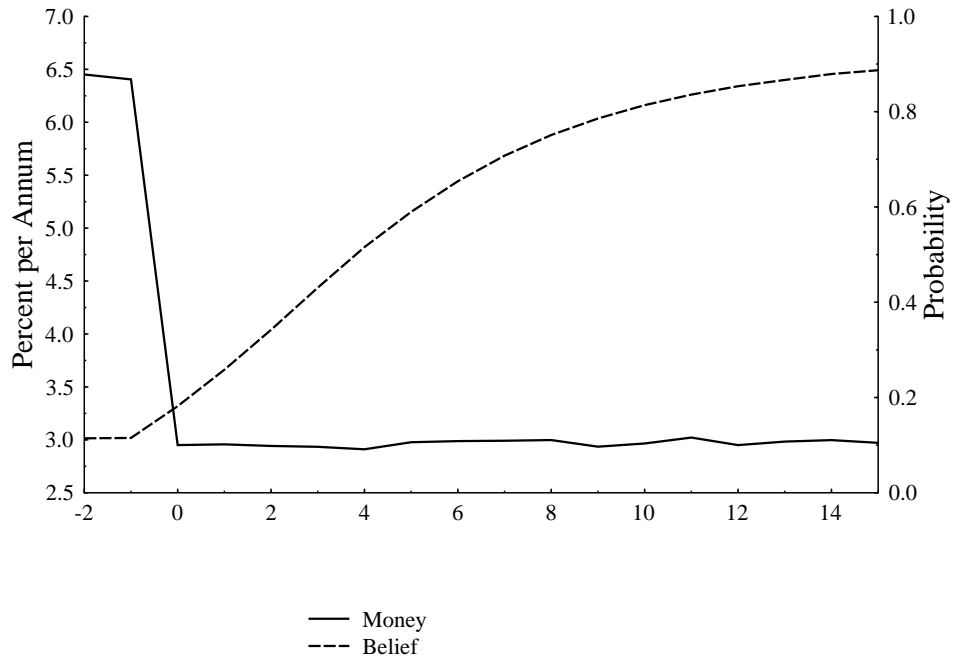


(a) Money Growth and Belief

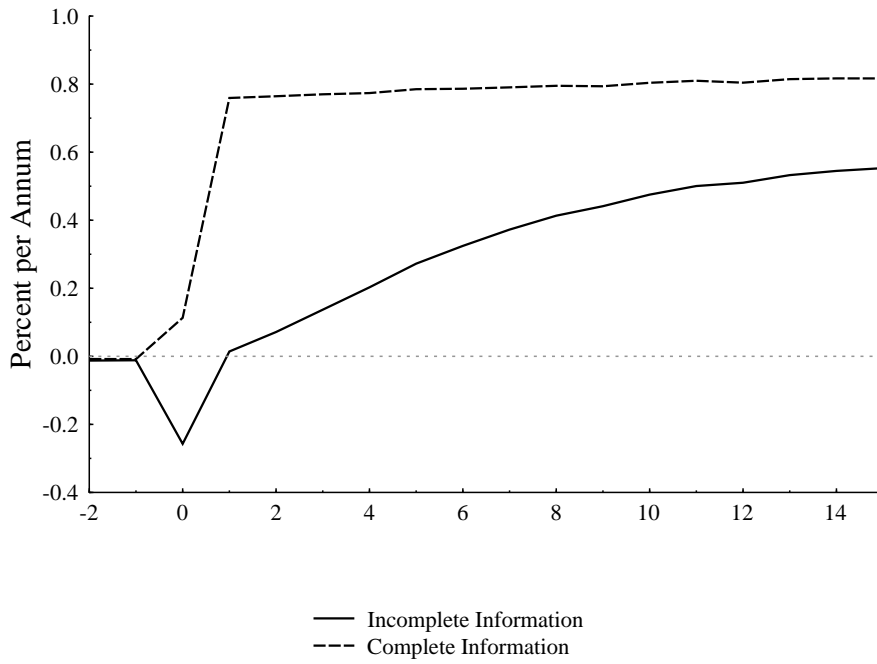


(b) Output and the Interest Rate

Figure 7: Disinflation Policy

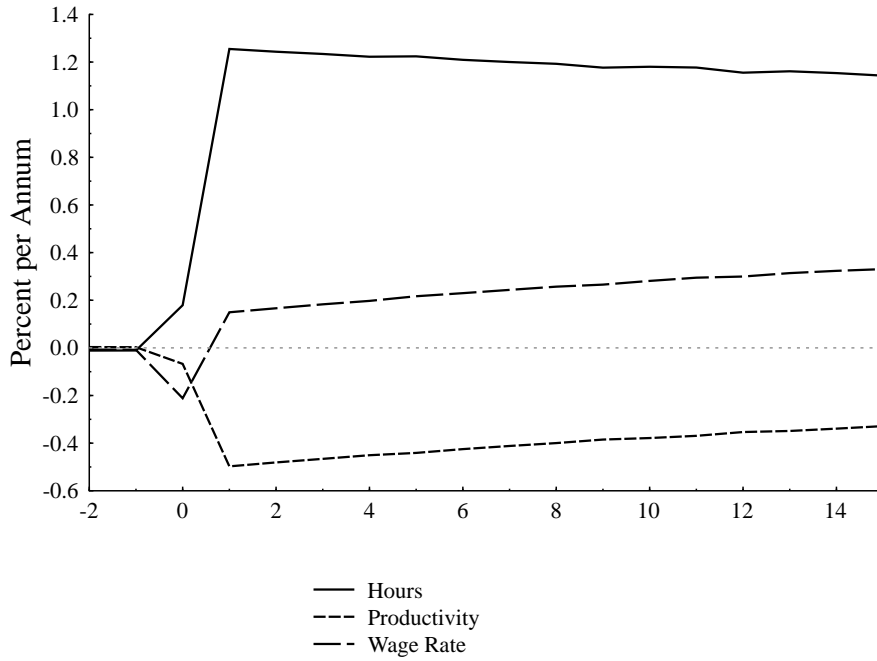


(a) Money Growth and Belief

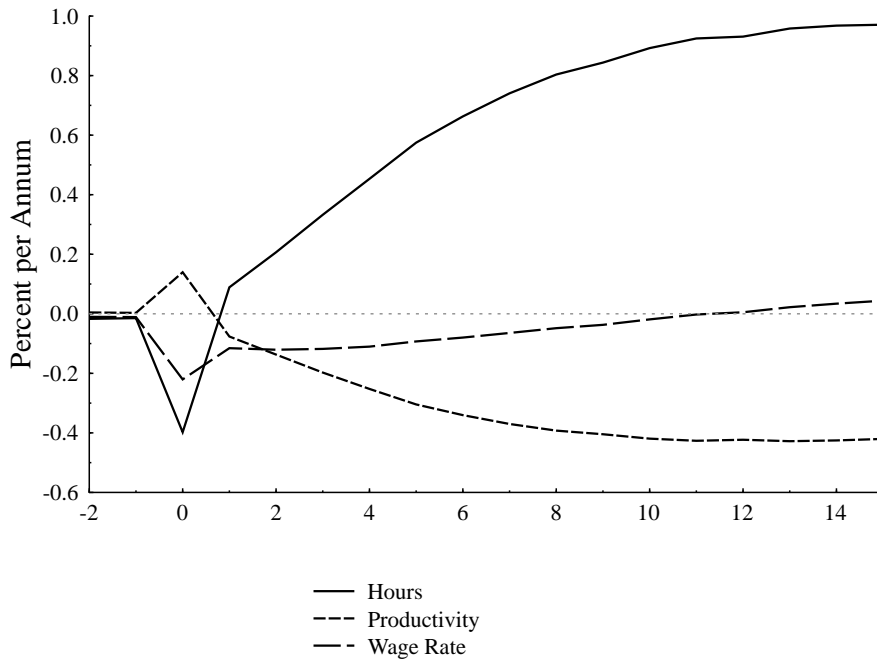


(b) Output

Figure 8: Disinflation Policy

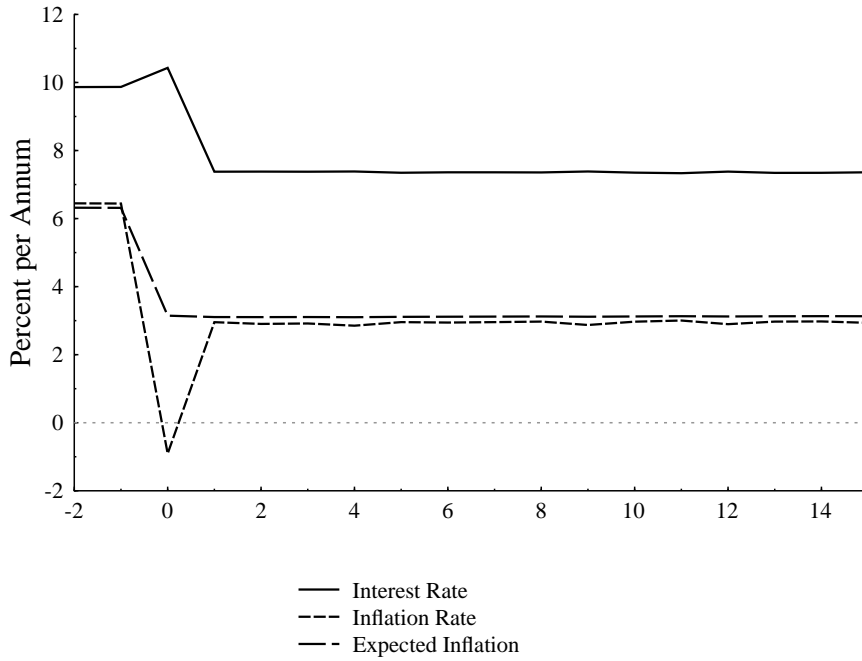


(a) Complete Information

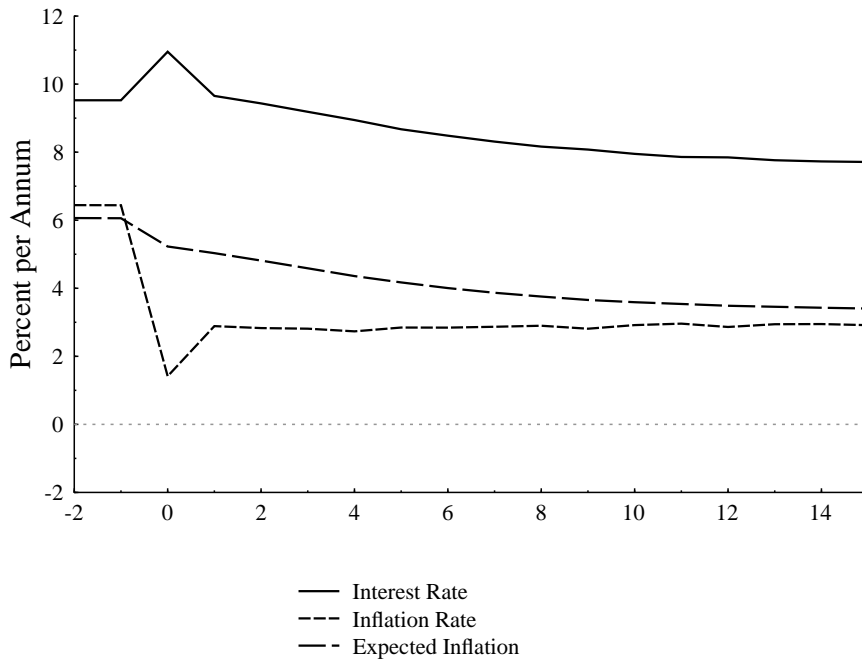


(b) Incomplete Information

Figure 9: Disinflation Policy



(a) Complete Information



(b) Incomplete Information

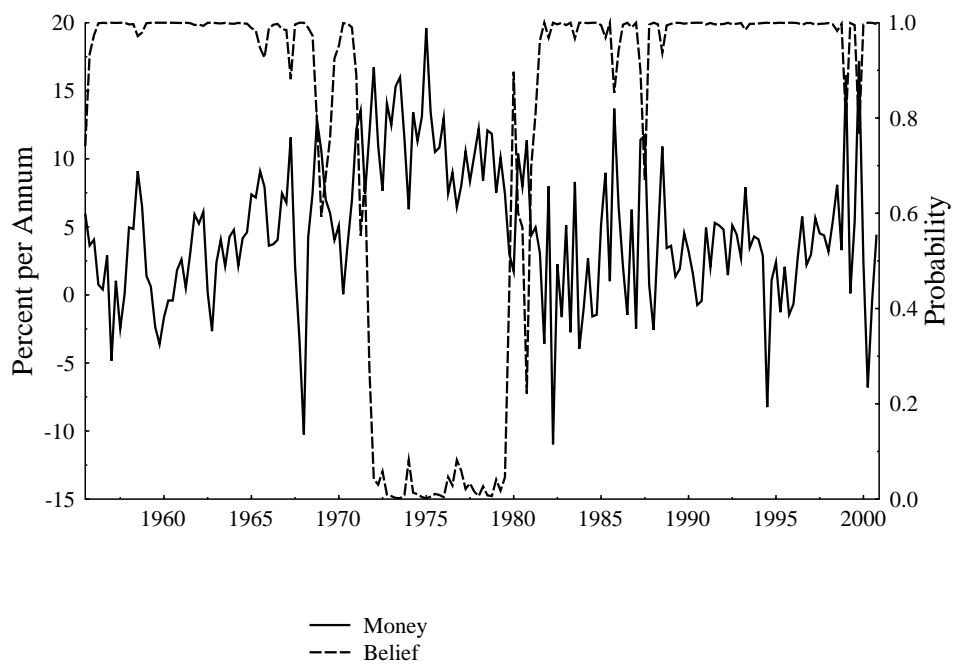
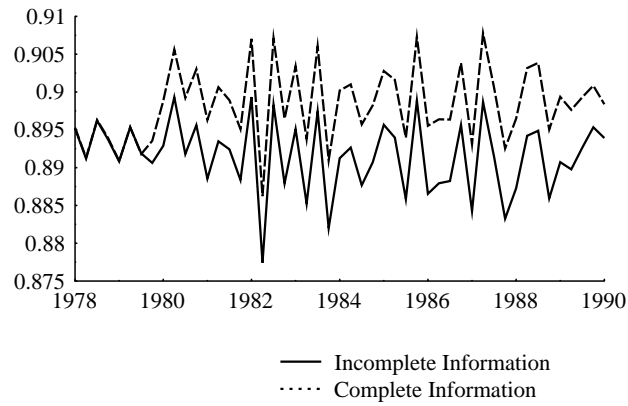
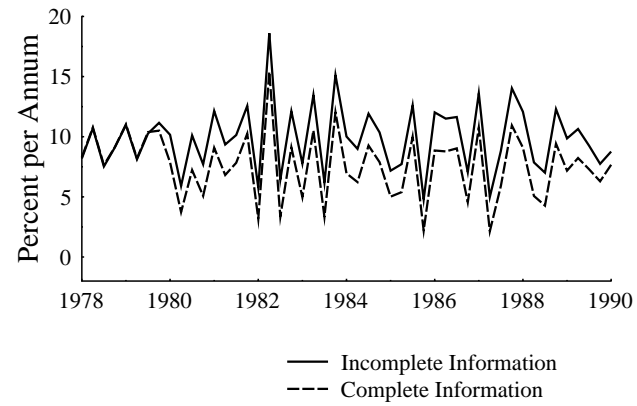


Figure 10: The growth rate in the monetary base is as described in Figure 1 (without smoothing). The initial belief was set to its unconditional mean.

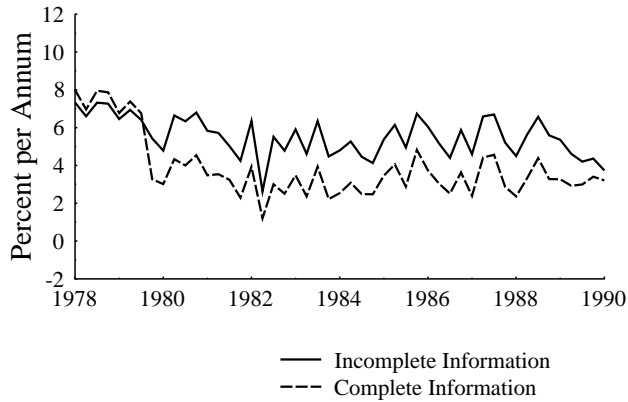
Figure 11: Actual Regime Change in 1979:4 – 2000 Parameter Estimates



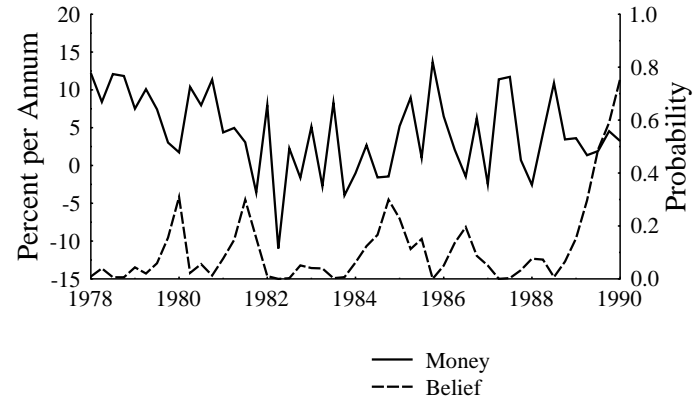
(a) Output



(b) Nominal Interest Rate

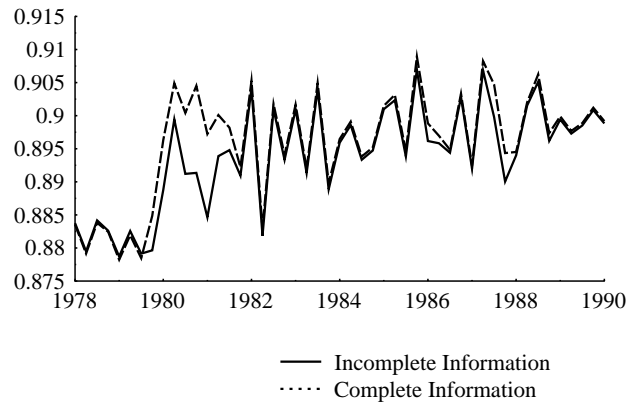


(c) Expected Inflation

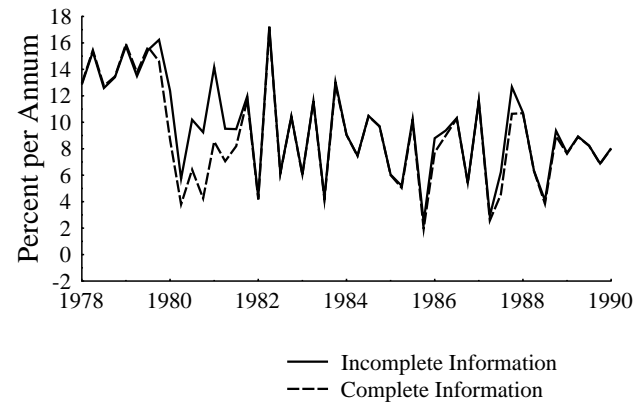


(d) Money Growth and Belief

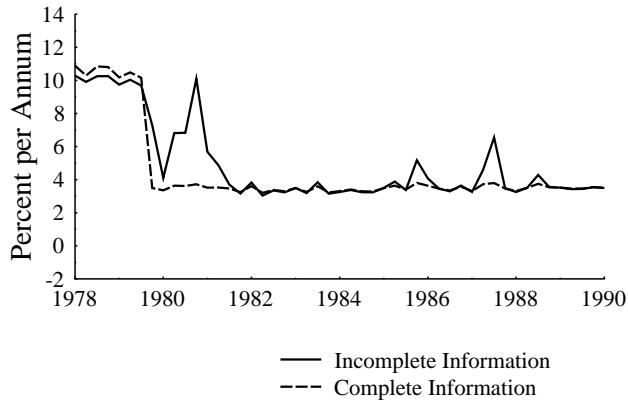
Figure 12: Actual Regime Change in 1979:4 – 1994 Parameter Estimates



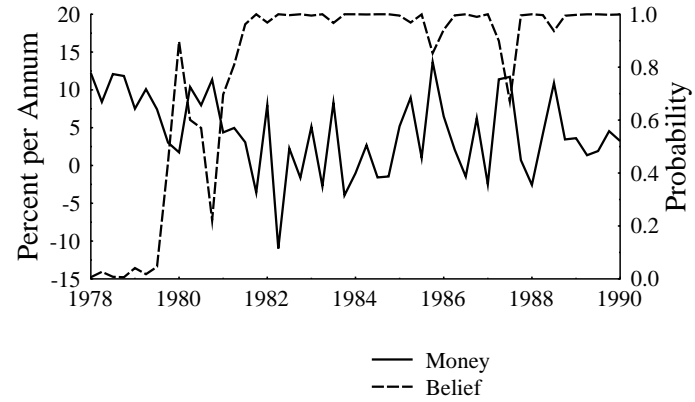
(a) Output



(b) Nominal Interest Rate



(c) Expected Inflation



(d) Money Growth and Belief

Monetary Policy Regimes and Beliefs*

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and

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April 2001

Abstract: This paper investigates the role of beliefs over monetary policy in propagating the effects of monetary policy shocks within the context of a dynamic, stochastic general equilibrium model. In our model, monetary policy periodically switches between low and high money growth regimes. When individuals are unable to observe the regime directly, they will have to form inferences over regime-type based on historical money growth rates. We show that for an empirically plausible money growth process, beliefs evolve slowly in the wake of a regime change. As a result, our model is able to capture some of the observed persistence of real and nominal variables following such a regime change.

Keywords: monetary policy, regime switching, beliefs

JEL classification codes: E52, E42, E31, E13

Forthcoming: *International Economic Review*

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1 Introduction

This paper is motivated by the following three observations. First, in many countries, monetary policy can be described roughly as having fluctuated between ‘loose-money’ and ‘tight-money’ regimes. These policy regimes manifest themselves as prolonged periods of alternately high and low inflation; see [Ricketts and Rose \(1995\)](#). Second, an identifiable change in monetary policy appears to induce a persistent ‘liquidity effect.’ [Romer and Romer \(1989\)](#), for example, find that episodes of contractionary monetary policy are characterized by prolonged periods of relatively high interest rates and depressed economic activity. Third, expectations of inflation appear to evolve sluggishly relative to inflation and money growth in the wake of a policy change; see [Dotsey and DeVaro \(1995\)](#). Furthermore, inflation expectations at times appear to be ‘biased’ in the sense of under- or over-predicting inflation for long periods of time; see [Thomas \(1999\)](#).

The purpose of this paper is to develop a dynamic general equilibrium model capable of accounting for these observations. We assess the extent to which the theory might be used to interpret Canadian data. From Figures 1–4, we see that the Canadian experience is generally consistent with the observations reported above. Figure 1 displays the growth rates for base money and the broader money aggregates. From the mid-1950s through to the early 1970s, base money growth averaged around 3 1/4% per annum. The 1970s were characterized by a more rapid expansion of base money, with growth rates averaging around 10% per annum. Since the early 1980s, base money has again averaged around 3 1/4% per annum. The broader monetary aggregates display a similar behavior. Figure 2 demonstrates how base money growth and inflation exhibit similar secular trends. Figures 3 and 4 provide evidence for the liquidity effect. In particular, notice how the rapid expansion of base money during the early 1970s is associated with a falling interest rate. Likewise, the sharp decline in base money growth during the late 1970s and early 1980s is associated with a rising interest rate. Figure 4 demonstrates how rising interest rates are typically associated with falling GDP growth rates. Finally, notice how the interest rate appears to lag money growth. To the extent that the interest rate embeds within it an expectation of inflation, this behavior suggests that inflation expectations appear to behave ‘adaptively,’ especially in the wake of significant changes in the persistent component of money growth.

Standard theory has a difficult time in accounting for the behavior of output and interest rates following an exogenous monetary policy shock; see [Christiano \(1991\)](#). The ‘limited participation’ models of [Lucas \(1990\)](#) and [Fuerst \(1992\)](#) are capable of generating a liquidity effect, but one which displays almost no persistence. [Christiano and Eichenbaum \(1992\)](#) and [Cooley and Quadrini \(1999\)](#), however, demonstrate how an *ad hoc* portfolio adjustment cost can generate persistence. [Cook \(1999\)](#) is also able to generate persistence by assuming that financial intermediation costs depend on some lagged measure of aggregate economic activity. None of these environments are able to account for sluggishly evolving inflation expectations.

In this paper, we hypothesize that the joint behavior of output, interest rates and inflation expectations might, in part, be attributable to the regime-switching nature of monetary policy. We do not ask *why* monetary policy is subject to regime shifts.¹ Instead, we wish to explore the implications for macroeconomic activity *given* the regime-switching nature of monetary policy. The crucial assumption we make is that the true monetary policy regime is not observable by private sector agents, and that the central bank cannot make credible announcements concerning

¹One possible explanation is provided by [Christiano and Gust \(2000\)](#).

regime-type. Consequently, if money growth varies for reasons other than regime changes, the private sector will have to form *beliefs* concerning the true nature of the prevailing monetary policy regime. These beliefs will presumably be formed rationally and will be updated on the basis of all available information (in particular, the historical realizations of actual money growth); as in [Cukierman and Meltzer \(1986\)](#), individuals will be faced with a signal-extraction problem. In such an environment, beliefs (and hence inflation forecasts) will evolve slowly relative to actual money growth rates and actual inflation. Furthermore, it is possible for inflation forecasts to remain above or below actual inflation rates for very long periods of time. At the same time, the sluggish expectation formation induces an endogenous sluggishness in the household portfolio decision, an effect that may contribute to the persistence of the liquidity effect following a regime change. The purpose of our paper is to investigate the extent to which the belief-formation mechanism described above can deliver a pattern of post-shock dynamics that are broadly consistent with the evidence.

Our results can be summarized as follows. First, when we apply [Hamilton's \(1989\)](#) Markov regime-switching estimator to Canadian base money growth, we find evidence of two distinct money-growth regimes: a tight-money regime, with average money growth equal to 3% per annum; and a loose-money regime, with average money growth equal to 6.5% per annum. Actual regime changes are estimated to be infrequent events, with regimes lasting on average around 10 years. As discussed in [Subsection 4.4](#), other sample periods yield estimates of the high money growth rate closer to 11%, and an average duration of the low money growth regime of around 30 years.

Second, conditional on this parameterization of monetary policy, we find that the 'credibility' of a monetary policy change (i.e., whether or not individuals know the true nature of monetary policy) can have important implications for the way a model economy adjusts to a change in monetary regime. In particular, without credibility, a disinflation policy may first induce recession and a prolonged period of 'above normal' interest rates. In addition, rational inflation forecasts can exceed actual inflation for long periods of time. A credible disinflation policy, on the other hand, induces a much quicker transition to a regime of lower interest rates and higher output.

Third, when applying the model to Canada's disinflation episode over the late 1970s and 1980s, we find that the noncredibility of policy may have had quantitatively important effects. Under our baseline parameterization, we find that an actual regime change in the fourth quarter of 1979 (from loose money to tight money) resulted in interest rates and inflation expectations that were on average two percentage points higher throughout the 1980s than they would otherwise have been if the disinflation policy was fully credible. Noncredibility is estimated to have cost the economy one-half percent of GDP in each year of that decade.

The paper proceeds as follows. The economic environment is described in [Section 2](#). In [Section 3](#), the stochastic process governing the evolution of base money is estimated and the model is calibrated. The key results of the paper are reported in [Section 4](#), which analyzes the behavior of the model economy following a monetary policy regime change. [Section 5](#) briefly reports the welfare benefit of a disinflation policy under different information structures. In [Section 6](#), we consider a particular episode in Canadian monetary history: the disinflation of the early 1980s. [Section 7](#) concludes.

2 Model

2.1 Households

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

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

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 labor (N_t) and leisure;

$$(2) \quad N_t + L_t = 1.$$

The allocation of the household's money balances is determined at the end of the previous period; this allocation decision will be described shortly.² A portion of these money balances, M_t^d , is committed to 'deposits' at the financial intermediary. These funds earn a return $R_t > 0$ with the principal and interest being paid at the end of period t .

The remainder of the household's funds are held in the form of 'transactions cash,' M_t^c , and are available to make current-period purchases. More specifically, each household is composed of a worker-shopper pair. At the start of the period, the pair separate with the shopper taking the household's cash to the output market while the worker visits the labor market in order to generate labor income. The shopper's purchases of consumption goods are constrained by the household's transactions cash; i.e.,

$$(3) \quad M_t^c \geq P_t C_t$$

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.³ Thus, end-of-period money income is given by

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

²Alternative formulations of the limited participation model allow households to divide their money holdings between 'cash' and 'deposits' at the beginning of the period, but before the realization of the money growth shock. For practical purposes, these different formulations are equivalent.

³We assume, without loss, that shares in business sector equity are not traded.

and money balances evolve according to:

$$(4) \quad M_{t+1}^c + M_{t+1}^d = Y_t + M_t^d + (M_t^c - P_t C_t).$$

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)–(4), 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.

Notice that the portfolio allocation decision made at the end of period t is made in reference to the *future* division of money between transactions cash and deposits (recall that M_t^c and M_t^d are predetermined as of date t). In particular, the household cannot condition its portfolio decision on any future monetary policy shock, but rather must make this choice on the basis of its expectation of future monetary policy. To the extent that expectations display any stickiness, so too will the portfolio decision. It is this effect that will serve to propagate the liquidity effect.

The Euler equations associated with household maximization are:

$$(5) \quad \frac{U_2(C_t, L_t)}{W_t} = \beta E_t \left\{ \frac{U_1(C_{t+1}, L_{t+1})}{P_{t+1}} \right\}$$

and

$$(6) \quad \frac{U_2(C_t, L_t)}{W_t} = \beta E_t \left\{ (1 + R_{t+1}) \frac{U_2(C_{t+1}, L_{t+1})}{W_{t+1}} \right\}.$$

Condition (5) 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 (6) governs the accumulation of deposits. Again, the left-hand side is the utility value of acquiring one more dollar at date t . If this dollar is deposited, rather than held as cash, then the individual has $(1 + R_{t+1})$ dollars in the subsequent period, which are valued at the margin by the (discounted) expected utility value of money at date $t + 1$.

2.2 Firms

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

$$(7) \quad 0 \leq Q_t \leq F(K_t, H_t),$$

where $F(K, H) = K^\theta H^{1-\theta}$. The capital stock is owned by the firm, but labor 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. Cash earnings do not arrive in time to finance the period wage bill. After repaying its business loans and paying for its capital expenditures, the firm remits any remaining cash as a dividend payment to households;

$$(8) \quad D_t^f = P_t Q_t - P_t I_t - (1 + R_t) W_t H_t.$$

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

$$(9) \quad K_{t+1} = (1 - \delta) K_t + I_t,$$

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

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

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

subject to (7)–(9), given a stochastic process for $\{P_t, W_t, R_t, \Delta_t | t \geq 0\}$ 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

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

The Euler equations governing the firm's optimization are:

$$(10) \quad P_t F_2(K_t, N_t) = (1 + R_t) W_t$$

and

$$(11) \quad \frac{P_t U_2(C_t, L_t)}{W_t} = \beta E_t \left\{ \frac{P_{t+1} U_2(C_{t+1}, L_{t+1})}{W_{t+1}} [F_1(K_{t+1}, N_{t+1}) + 1 - \delta] \right\}.$$

Condition (10) equates the marginal product of labor with the real cost of labor to the firm (which includes its interest rate payments necessary to finance the period labor input). Condition (11) governs the accumulation of capital.⁴ 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.

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 deposits M_t^d provided by households, is supplied

⁴Note that the consumers' Euler equations have been used in deriving (11).

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

$$(12) \quad \begin{aligned} D_t^b &= (1 + R_t) \left[M_t^d + X_t \right] - (1 + R_t) M_t^d \\ &= (1 + R_t) X_t \end{aligned}$$

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. Money growth evolves according to:

$$(13) \quad \mu_t - \hat{\mu}_t = \psi(\mu_{t-1} - \hat{\mu}_{t-1}) + \varepsilon_t, \quad |\psi| < 1$$

where $\hat{\mu}_t$ is the ‘long-run’ money growth rate at date t and ε_t is a random disturbance (monetary control error) drawn from a Normal distribution function $N(0, \sigma_t^2)$.

A *monetary policy regime* is characterized by a ‘long-run’ rate of monetary expansion $\hat{\mu}_t$, and a standard deviation of the monetary control error, σ_t . For simplicity, it is assumed that there are only two regimes:

$$(\hat{\mu}_t, \sigma_t) \in \{(\mu_L, \sigma_L), (\mu_H, \sigma_H)\}.$$

where $\mu_L < \mu_H$. (There is no presumption that $\sigma_L < \sigma_H$.) Monetary policy regimes switch back and forth over time according to a Markov transition law with known parameters:

$$(14) \quad \phi_{ij} = \Pr[(\hat{\mu}_t, \sigma_t) = (\mu_j, \sigma_j) | (\hat{\mu}_{t-1}, \sigma_{t-1}) = (\mu_i, \sigma_i)] \quad i, j = L, H.$$

Of course, $(\hat{\mu}_t, \sigma_t)$ represents a ‘long-run’ regime only to the extent that ϕ_{LL} and ϕ_{HH} are in some sense ‘close’ to unity.

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

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

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 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 $\Gamma_t = \{\mu_t, \mu_{t-1}, \mu_{t-2}, \dots\}$, together with any prior information.

Let $b_t \equiv \Pr[\hat{\mu}_t = \mu_L | \Gamma_t]$ 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):

$$(15) \quad b_t = \frac{g_L(b_{t-1}, \mu_t)}{g_L(b_{t-1}, \mu_t) + g_H(b_{t-1}, \mu_t)}$$

where

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

where $f_i(\varepsilon)$ for $i \in \{L, H\}$ denotes the density function of the monetary control error in each regime. The function g_L represents the likelihood that the current money growth rate, μ_t , was generated under the tight-money regime, given the prior belief b_{t-1} . The first term is the product of: (1) the probability attached to being in the tight-money regime last period, (2) the probability of no regime transition, and (3) the probability of observing the current money growth rate given no transition. Likewise, the second term is the product of: (1) the probability attached to the loose-money regime being in place last period, (2) the probability of making the transition from the loose-money to the tight-money regime, and (3) the probability of seeing the current money growth rate given this transition. Similarly, g_H is the likelihood that current money growth was generated under the loose-money regime.

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 (15) lie strictly between 0 and 1, an individual will never be absolutely certain as to the central bank's type.

Second, for parameters like those reported below, learning *will* occur. For example, suppose that at time t an agent assigns a high probability to the tight-money regime ($b_t \approx 1$). 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 money growth rates associated with the low money growth regime 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 realized money growth rates that are more likely to have come from the high money growth regime. Thus, individuals may incorrectly infer a change in monetary policy when there has, in fact, been none.

Finally, since a regime is associated with both a money growth rate and a variance of the monetary control error, agents will in general use not only the current *level* of money growth but also its *variability* in forming their beliefs. For example, if individuals place a large likelihood on the ‘tight’ money regime being in place, they may find the current money growth rate ‘unusual’ because it is closer to the mean growth rate of the ‘loose’ money regime and/or because the likelihood that the money control error is drawn from the ‘tight’ money regime is remote.

2.7 Expectations

Thus far, no explicit distinction has been 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 $z_{t+1} = z(\varepsilon_{t+1})$ is given by

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

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

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

for $b_t \in (0, 1)$.

2.8 Competitive Equilibrium

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

$$\{C_t, N_t, L_t, M_{t+1}^c, M_{t+1}^d, Q_t, H_t, I_t, K_{t+1}, D_t^f, D_t^b | t \geq 0\}$$

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

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

which represent the goods, money, loans and labor markets, respectively.

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 labeled the *anticipated inflation effect* (or the Fisher effect) and the *liquidity effect*. Below, we discuss both effects in turn.

Consider an unanticipated, but persistent, reduction in money growth (for example, the implementation of a lower long-run inflation target). Under complete information, individuals rationally lower their inflation forecasts accordingly. Since inflation acts as a tax on labor earnings, the anticipation of lower inflation increases the expected return to working and hence leads to an increase in the supply of labor (for any given real wage). Under incomplete information, inflation expectations initially remain high (relative to the case of complete information) as individuals are unsure as to whether the lower money growth realization represents an actual regime change, or just a transitory deviation from the current regime. In this latter case, the labor supply response will be muted.

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 the interest rate in an attempt to secure the cash loans that they need in order to finance the period labor input. Normally, raising the interest rate would 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, the interest rate rises leading to a fall in labor demand and a decline in output. In this way, the liquidity effect causes employment and output to contract and the interest rate to rise. The liquidity effect on employment works in an opposite direction to the anticipated inflation effect (the period interest rate is determined primarily by the liquidity effect); in equilibrium either effect may dominate depending on the configuration of the model's parameter values.⁵ However, because the anticipated inflation effect is muted in the incomplete information environment, it is more likely that the liquidity effect will dominate in this case.

In the complete information environment, the household's portfolio decision is influenced by the expected future reduction in loanable funds and lower inflation; i.e., there will be a shift away from transactions cash into deposits. For this reason, the liquidity effect will be short-lived. But in

⁵See [Christiano \(1991\)](#) for further details.

the incomplete information environment, the portfolio adjustment displays an endogenous stickiness owing to the persistence in beliefs. Consequently, future deposits – and hence future loanable funds – will be curtailed relative to the complete information case; i.e., households wish to maintain a relatively large supply of transactions cash because they expect inflation to remain high. That is to say, they initially place a large weight on the current low money growth rate being a transitory deviation. The sluggish portfolio response of the household sector means that in the subsequent period, when money growth is once again low (recall that we are assuming that the regime change did in fact occur), financial markets will once more be ‘surprised’ by the unanticipated shortfall in loanable funds even in the absence of any further money shock. These ‘surprises’ will continue as long as beliefs take time to adjust. In this way, the liquidity effect may persist.

2.9 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:

$$m_t^c \equiv \frac{M_t^c}{M_t}, \quad m_t^d \equiv \frac{M_t^d}{M_t}, \quad p_t \equiv \frac{P_t}{M_t}, \quad w_t \equiv \frac{W_t}{M_t}, \quad x_t \equiv \frac{X_t}{M_t}.$$

Using the labor market clearing condition to eliminate H_t , the system of equations may now be written as:

$$(16) \quad p_t C_t = m_t^c$$

$$(17) \quad (1 + \mu_t) \frac{U_2(C_t, 1 - N_t)}{w_t} = \beta E_t \left\{ \frac{U_1(C_{t+1}, 1 - N_{t+1})}{p_{t+1}} \right\}$$

$$(18) \quad (1 + \mu_t) \frac{U_2(C_t, 1 - N_t)}{w_t} = \beta E_t \left\{ (1 + R_{t+1}) \frac{U_2(C_{t+1}, 1 - N_{t+1})}{w_{t+1}} \right\}$$

$$(19) \quad p_t F_2(K_t, N_t) = (1 + R_t) w_t$$

$$(20) \quad \frac{p_t U_2(C_t, 1 - N_t)}{w_t} = \beta E_t \left\{ \frac{p_{t+1} U_2(C_{t+1}, 1 - N_{t+1})}{w_{t+1}} [F_1(K_{t+1}, N_{t+1}) + 1 - \delta] \right\}$$

$$(21) \quad 1 + \mu_t = w_t N_t + m_t^c$$

$$(22) \quad C_t + K_{t+1} = F(K_t, N_t) + (1 - \delta) K_t$$

where the restrictions $m_t^c + m_t^d = 1$ and $x_t = \mu_t$ have been employed above. The system (16)–(22) now characterize a stationary stochastic process $\{C_t, N_t, K_{t+1}, R_t, p_t, w_t, m_t^c\}$.⁶

⁶Equilibrium decision rules and pricing functions are obtained computationally by applying an Euler equation iteration technique developed by [Coleman \(1991\)](#).

3 Calibration

The parameters of the model are given by

$$\begin{aligned} \text{Preferences: } & \beta, \omega, \gamma \\ \text{Technology: } & \theta, \delta \\ \text{Monetary Policy: } & \mu_L, \mu_H, \phi_{LL}, \phi_{HH}, \psi, \sigma_L, \sigma_H. \end{aligned}$$

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 the regime switching model of Hamilton (1989) to data on per capita base-money growth for Canada over the sample period 1955:2–2000:4. 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 behavior of the series.⁷

The actual estimation was undertaken with a GAUSS program written by Hamilton. The parameter estimates are given in Table 1.⁸

Table 1: Parameter Estimates, Sample Period 1955:2–2000:4

<i>Parameter:</i>	μ_L	μ_H	ϕ_{LL}	ϕ_{HH}	ψ	σ_L^2	σ_H^2
<i>Estimate:</i>	0.0074	0.0161	0.9741	0.9780	0.4305	0.00004670	0.00019120
<i>Standard Error:</i>	0.0015	0.0026	0.0246	0.0194	0.0729	0.00001051	0.00002864

The estimation procedure identifies two regimes with the following features. In the ‘tight-money’ regime, money growth averages 0.74% per quarter (3.00% per annum) with a standard deviation of 0.68%, while in the ‘loose-money’ regime, money growth averages 1.61% per quarter (6.50% per annum) with a standard deviation of 1.38%. In other words, a loose-money policy is associated not only with higher money growth, but also more volatile money growth (although, volatility relative to mean is roughly the same across the two regimes). Furthermore, the estimation identifies long-term trends in each regime (as opposed to trends that fluctuate at business cycle frequencies); i.e., the average duration of each regime is roughly ten years $(1 - 0.976)^{-1} \approx 42$ quarters. The autoregressive component of money growth within each regime is estimated to be only moderately persistent (0.43).

Figure 5 depicts the actual money growth series together with the estimated belief that the monetary authority is following the tight-money program at any given date, conditional on all currently available information (i.e., historical money growth rates and the initial belief). The estimation suggests that in the early part of the sample (up until around 1967), individuals were

⁷As in the Kalman filter, the time path of an observed series is used to draw inferences about an unobserved state variable. While the Kalman filter is a linear algorithm for generating estimates of a continuous unobserved state variable, the Hamilton filter is a nonlinear algorithm and provides inferences over an unobserved discrete-valued variable.

⁸The initial belief b_0 was set equal to its unconditional mean: $(1 - \phi_{HH}) / (2 - \phi_{LL} - \phi_{HH})$.

confident that they were operating under a tight-money regime. From 1967-72, there appears to be considerable uncertainty over policy regime in the sense beliefs were fluctuating widely between the two regimes. By 1972, belief in the loose-money regime had become entrenched. While retrospective studies of Canadian monetary policy date the shift back to a low inflation regime to the early 1980s, the estimates in Table 1 suggest that people had difficult time in believing that an actual change in policy had been implemented.⁹ In fact, throughout the entire 1980s, confidence in the tight-money regime fluctuated significantly, never surpassing 30%, in spite of the fact that money growth remained low (relative to the 1970s). The puzzling behavior of beliefs over this period can be rationalized by noting that while money growth tended to be low, it also displayed considerable volatility – a feature that is associated with the loose-money regime. Not until 1990 did the public gain confidence in the tight-money regime; this belief remained fairly stable with brief exceptions during 1994-95 and at the very end of the sample period. These two exceptions reveal two very different ways in which confidence in the tight-money regime may be adversely affected. In the latter part of the sample, we see that relatively high and volatile money growth rates can trigger a change in beliefs. During the 1994-95 sample period (and in other periods as well), we see that money growth is relatively low, a large decline in the money growth rate might signal a change to a *loose-money* regime (since big movements in money growth – in any direction – are more commonly associated with loose-money).

4 Results

At the end of Subsection 2.6, we noted that when individuals form beliefs over the current regime, they will use information not only about the *level* of money but also its *variability* since regimes differ in both their mean growth rate and also the standard deviation of the monetary control error. Consequently, we need to perform stochastic simulations of the model to afford agents the opportunity to use information about the variability of money when they form their beliefs.¹⁰ The impulse-responses presented below are the *averages* taken over 10,000 simulations of the model.

4.1 Transitory Shocks

Figure 6 displays the impulse-response functions for money growth, beliefs, output, and the interest rate following a positive one-standard-deviation shock in the transitory component of money growth in the incomplete information environment and beginning in the tight-money regime. In the impact period of the shock, the interest rate drops over 1 percentage point, while output rises by almost 0.2 percent (relative to its trend under the tight-money regime). Just prior to the shock, belief in the tight-money regime is hovering just over 90%; in the impact period of the expansionary shock, belief in the tight-money regime falls modestly to 85%.

Under the complete information environment (not displayed), the dynamics basically stop here; i.e., the money shock does not propagate. In contrast, the money shock does appear to propagate

⁹As discussed in Subsection 4.4, different sample periods yield parameter estimates that give a different picture of this period. In particular, for a sample period ending 1994:4, beliefs shift back to the low money growth regime by 1982.

¹⁰We are grateful for the comments of an anonymous referee that led us to reconsider how we generated our impulse-responses.

when information is incomplete, although not in the sense that conventional wisdom would dictate. In particular, following the very short-lived economic boom generated by the transitory increase in money growth, the economy enters into a prolonged (if mild) period of recession and relatively high interest rates. What is happening here is that the transitory increase in money growth is partly perceived to be ‘permanent’, owing to the fact that individuals ‘mistakenly’ attach some weight to the possibility that the observed increase in money growth reflects a transition to a loose-money policy.

4.2 A Credible Disinflation Policy

This section considers the economy’s response to a change in monetary policy regime, moving from loose-money to tight-money, in the complete information environment. In the period of the policy change, annual money growth drops from 6.5% to 3.0%. In the impact period of the shock, the interest rates rises a modest 0.6 percentage points, while inflation dropping dramatically by 7.3 percentage points (see Figure 9(a)). Inflation expectations drop immediately in accordance with the new (and known) monetary policy regime. In the second period following the money shock, the interest rate drops to its new ‘long run’ level, while inflation rises to its new ‘long run’ level, both of which are significantly lower than their levels under the previous loose-money regime.

Figure 8(a) records the effect of the change in policy regime on a number of labor market variables. In the impact period of the shock, the unexpected contraction in cash actually causes a moderate economic boom, with employment rising by just over 0.2%. How does one explain the rise in employment in face of the rise in interest rates (which supposedly contracts the demand for labor)? The answer lies in the behavior of labor supply. Recall that inflation expectations drop immediately in the impact period of the shock; leading to a reduction in the anticipated ‘inflation tax’ on labor market earnings and hence results in an increase in the supply of labor at any given wage. In other words, while the demand for labor contracts, the expansion in the supply of labor more than offsets this shift, leading to an expansion in employment (and a drop in real wages). Labor productivity falls in the impact period as employment expands relative to a fixed capital stock.

In the second period following the money shock, employment rises rapidly to its new ‘steady state’ level (about 1.2% above its previous level). This rapid expansion in employment can be attributed to the significant drop in interest rates (and consequent expansion in labor demand) that follow as inflation expectations drop in accordance with the new tight-money regime. Higher labor demand implies higher real wages for workers, but labor productivity actually remains lower than before, reflecting the fact that the capital stock hardly responds at all to the change in policy regime.¹¹

4.3 A Noncredible Disinflation Policy

This section now considers how the economy reacts to the same change in monetary policy regime, but under the assumption of incomplete information; the results are reported in Figures 7, 8(b) and 9(b). As in the experiment considered above, annual money growth drops from 6.5% to 3.0%.

¹¹Note that because firms must borrow cash to finance the labor input, the interest rate drives a wedge between the real wage and labor productivity so that these latter two variables need not move in the same direction.

What are agents thinking upon observing such large decline in money growth? Belief in the loose-money regime is initially high (around 90%). Note that while a 3.5 percentage point drop in money growth is large, it is not inconceivable for people to believe that such a realization is being generated by the relatively volatile loose-money regime. Consequently, belief in the tight-money regime rises only modestly and expectations of inflation fall by only a very small amount. Notice that actual inflation drops significantly in the impact period of the shock, but that the drop is dampened somewhat relative to the complete information environment. With a noncredible disinflation policy, the liquidity effect is now much stronger: the interest rate jumps by almost 1.5 percentage points (more than twice as large as is predicted to occur with a credible disinflation).

In the labor market, the ‘sticky’ inflation expectations imply that there is not much effect on labor supply behavior (workers do not expect any great changes in the inflation tax on their earnings).¹² On the other hand, the demand for labor falls significantly in line with the sudden contraction of liquidity (and higher financing costs). Reduced labor demand results in lower employment and lower real wages, contrary to what is predicted to happen when the disinflation policy is credible.

What is especially interesting to note here is how the signal extraction problem endogenously propagates the effects of the regime change forward in time; i.e., the economy’s dynamic response to the policy change is now much more protracted relative to the complete information environment. To begin, note that the interest rate remains above its initial level even in the period following the shock and subsequently takes several quarters before it closely approaches its new ‘steady state’ level. The transition path for the interest rate mirrors that of inflation expectations, which evolve sluggishly as people only gradually put greater faith in the likelihood of an actual regime change. Furthermore, observe that expectations of inflation appear to be ‘biased’ in the sense of consistently overpredicting actual inflation throughout the transition period; such behavior appears to be consistent with the empirical evidence reported in [Dotsey and DeVaro \(1995\)](#).

The exact mechanism at work here is as follows. The unanticipated shortfall in liquidity is largely interpreted as a transitory ‘monetary control error’ generated by the loose-money regime. Consequently, people do not expect a similar shortfall in liquidity (and correspondingly high interest rate) to recur in the future and so end up keeping ‘too much’ money for transactions purposes and ‘not enough’ money in their interest-bearing saving accounts (where this cash can end up as loanable funds for liquidity strapped firms). Of course, since the tight-money regime is in fact in place, financial markets are once again ‘surprised’ by a shortfall in liquidity (despite the fact that no further shock has occurred). The size of this surprise is smaller in later periods than on impact since beliefs (and hence portfolio decisions) do adjust in the ‘correct’ direction, although in only a small degree (relative to the size of the adjustment that would have taken place if people actually believed the policy change). In this way, a ‘one-time’ regime change can induce a dynamic response similar to what would occur if the economy was hit by a sequence of progressively smaller surprises in money growth.

¹²As pointed out by a referee, including wage income in the household’s cash-in-advance constraint eliminates the unanticipated inflation effect on the labor supply decision. This modification of the cash-in-advance constraint has two other effects. First, the impulse-responses for output look more similar, with a disinflationary policy leading to a recession in both environments. Second, the liquidity effect is generally weaker. Our results should be viewed with this caveat in mind.

4.4 Sensitivity Analysis

Our parameter estimates are sensitive to the sample period used. For samples ending between 1987 and 2000, roughly a quarter have parameter estimates similar to those reported in Table 1. The remaining three-quarters of the samples have parameter estimates similar to those in Table 2 where the sample ends in 1994:4.

Table 2: Parameter Estimates, Sample Period 1955:2–1994:4

<i>Parameter:</i>	μ_L	μ_H	ϕ_{LL}	ϕ_{HH}	ψ	σ_L^2	σ_H^2
<i>Estimate:</i>	0.0082	0.0274	0.9920	0.9633	0.2461	0.00011298	0.00005918
<i>Standard Error:</i>	0.0012	0.0019	0.0088	0.0328	0.0787	0.00001458	0.00001602

There are three important differences between the parameter estimates reported in Table 1 and those in Table 2. First, the growth rate in the ‘loose’ money regime is much higher: around 11% per annum versus 6.5%. Consequently, the difference in the mean growth rates across regimes is much larger, a fact that serves to make it easier for agents to infer that a regime change has taken place. Second, the low money growth regime is associated with the higher standard deviation of the monetary control error; in Table 1, the low money growth regime also had low variability. Finally, the probability of staying in the low money growth regime is higher for the 1994 sample than the 2000 sample. For the 1994 sample, the average duration of the low money growth regime is over 30 years compared with the average duration of 10 years associated with the 2000 sample.

Figure 10 plots Canadian base growth along with the belief generated by using the parameters for the sample ending in 1994. Compared to Figure 5 (parameters for the 2000 sample), individuals continue to attach a high probability to the low money growth regime well into the 1970s. In the 1980s, they are also much quicker to conclude that the low money growth regime is in place. By the end of 1982, they are pretty well convinced that they are dealing with the low money growth regime. This episode will be discussed in greater detail in Section 6.

Qualitatively, the parameter estimates for the sample ending in 1994 generate impulse-responses that are quite similar to those associated with parameters for the 2000 sample. *Quantitatively*, there are three important differences. First, the impact effect of a regime change is substantially larger for the 1994 parameters, since the change in the ‘long run’ growth rate of money is now much larger. A disinflation experiment like that considered in Subsection 4.2 now implies a fall in the annual growth rate of money of 8 percentage points – double that implied by the 2000 parameter estimates. As a result, under incomplete information, the nominal interest rate response is roughly double that presented in Figure 9. The response of other variables is also enhanced, but to a lesser degree.

Second, under incomplete information, it takes individuals much less time to infer that a regime change has taken place. For example, following a disinflation policy, most of the change in beliefs occurs within four quarters of the regime change whereas Figure 7(a) displays a far more protracted adjustment in beliefs.

Third, since the transition probabilities in Table 2 are quite different, the effects of a disinflation are somewhat different from those following an inflationary episode. In particular, the probability of switching from the low to the high money growth regime is less than 1% per quarter compared

with around 4% for the reverse transition. The adjustment in beliefs following a switch from low to high money growth is, then, somewhat more protracted, although not as drawn out as for the 2000 parameter estimates.

Overall, these results highlight the factors that are important for beliefs to adjust sluggishly following a regime change. First, beliefs will adjust quite rapidly if regimes are distinctly different. By way of example, if the monetary control error is fairly small, then the larger is the difference in the mean money growth rates, the easier it is for agents to identify a regime change. Second, when regime changes are infrequent (the probabilities ϕ_{LL} and ϕ_{HH} are close to unity), the belief variable will tend to converge to either zero or one. In this case, it takes longer for beliefs to adjust following a regime change.

5 Welfare Analysis

In this section, we attempt to measure the welfare benefit of implementing a disinflationary policy. To begin, for $\lambda = 0$, we compute the value of living under the loose-money regime as:

$$V^H(\lambda) = \sum_{t=0}^{\infty} \beta^t U(c_t^H + \lambda y_t^H, \ell_t^H)$$

where c_t^H is average consumption, y_t^H is average output, and ℓ_t^H is average leisure under the loose-money regime, where the averages are computed over the 10,000 simulations used for the impulse-responses. The payoff V^H can be computed for both the complete and incomplete information environments.

Next, suppose that the loose-money regime has been in place for a long time, but at date 0 the regime switches permanently to tight-money. The value of this transition is:

$$V^{HL} = \sum_{t=0}^{\infty} \beta^t U(c_t^{HL}, \ell_t^{HL})$$

The superscripts denote a transition from high to low money growth.¹³ For any such realization of money growth, we can compute the welfare benefit as the (unique) value of λ solving

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

The parameter λ represents the fraction of income that an individual living in the high money growth regime would, in retrospect, have been willing to sacrifice for the opportunity of living with the disinflation policy. In the tables below, we compute the average λ across 10,000 simulated regime changes.

Table 3 summarizes the welfare benefit of switching to a tight-money regime (using parameters for the sample ending in 2000). For comparison with the previous literature, the welfare benefit is also calculated ignoring transitional dynamics. There are separate entries for the complete and incomplete information environments since each has slightly different stationary states (under incomplete information, individuals are never quite sure which regime they are in).

¹³The infinite sum is approximated by assuming that after 90 periods the economy has settled into a new stationary state, and assuming that consumption and leisure remain at those levels thereafter.

Table 3: Welfare Benefit of a Disinflation

	<i>Welfare Benefit</i> ($\lambda \times 100$)	
	<i>Complete Information</i>	<i>Incomplete Information</i>
<i>Parameters for Sample Ending 2000:4</i>		
No Transitional Dynamics	0.1128	0.0676
With Transitional Dynamics	0.0398	0.0313
<i>Parameters for Sample Ending 1994:4</i>		
No Transitional Dynamics	0.2461	0.1833
With Transitional Dynamics	0.0678	0.0452

To begin, notice that the welfare figures computed across ‘long-run’ states are in the neighborhood of those reported in the literature (e.g., [Cooley and Hansen, 1989](#)); i.e., around 0.1% of income (in perpetuity) for the 3.5 percentage point fall in inflation (from 6.5% to 3%). Accounting for the transitional path has a significant impact on the measured welfare benefit of disinflation. For both the complete or incomplete information cases, ignoring transitional effects overstates the welfare benefit by over a factor of two. Using the parameter estimates for the sample ending in 1994 gives a fairly similar picture; see [Table 3](#). Ignoring the transitional effects, the welfare costs are comparable to those in the literature. Including the transition path reduces these costs by roughly a factor of 4. 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. There are two effects at work. First, there is a difference in the stationary states associated with either high or low money growth since under incomplete information individuals are never certain which regime they are dealing with. Second, in the incomplete information environment, individuals take a while to figure out that a regime-switch has occurred. Consequently, they continue to act for some time as if a relatively high inflation tax is still in place, thus delaying their adjustment to the new regime.

6 Canada’s Disinflation Episode

Through the mid- to late-1970s and early-1980s, the Bank of Canada declared its intention to reduce inflation. In 1975, the Bank of Canada adopted a policy of “Gradualism” under which it announced growth rate targets for M1. The middle of the target range was gradually reduced in an effort to control inflation. This policy was largely a failure as inflation rose again in the late 1970s; see [Figure 2](#). In retrospect, it appears that the Bank of Canada switched to a tight-money regime sometime in the late-1970s or early-1980s. By 1985, inflation had fallen from double digits to around 3% per annum, and has been fairly stable since then. However, this policy change has also been credited with contributing to the depth and length of the 1981–82 recession, as well as the high interest rates that have prevailed throughout the 1980s.

In this paper, we have identified one mechanism by which a noncredible disinflation could

contribute to below-normal output levels and above-normal interest rates for an extended period of time. Based on our parameter estimates for the sample period ending 2000:4, it would seem that individuals did not believe that the Bank of Canada had in fact switched to a low money growth regime until the late 1980s; see the belief series plotted in Figure 5. 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 experiment considered 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 both the complete and incomplete information environments.¹⁴ Any discrepancy that exists between the predictions of these two versions of the model is then interpreted as an estimate of the quantitative impact of noncredibility.

As regime-type is not observable, the predictions of the model under the complete information environment must be conditioned on the date at which monetary policy is assumed to have switched. Below, we report results assuming that the switch to tight-money occurred in 1979:4. We have experimented with alternative dating of this regime switch, and have found that the qualitative nature of the results are not sensitive to the specific date of the regime switch.

Figure 11 plots the predicted path for output, the interest rate, expected inflation, and beliefs, together with the actual base money growth rate realizations of the Canadian economy over the period 1978:1–90:1, for both complete and incomplete information environments. Judging from these figures, it appears that the noncredibility of policy had a significant impact on the behavior of the economy. Had the disinflation policy in 1979:4 been credible, on average inflation forecasts would have been 3.35 percentage points lower, and interest rates would have been 5 percentage points lower. Furthermore, our results suggest that over this entire decade, real output was depressed by approximately half a percent due to the noncredibility of the Bank of Canada.

Using the parameter estimates for the sample ending in 1994 leads to a somewhat different interpretation of events in Canada through the 1980s; see Figure 12. By mid-1981, beliefs have switched over to the low money growth regime, although there are subsequent quarters when there are substantial drops in beliefs. Under this parameterization, the contribution of monetary policy noncredibility is confined to the two year period between mid-1979 and mid-1981. Over this period, noncredibility is found to have lowered the level of output by an average of 0.8%.

The discussion in Subsection 4.4 provide some insight into why our interpretation of Canadian monetary policy in the 1980s differs so much depending on which set of parameter values we use. From either Figure 5 or Figure 10, it can be seen that money growth was quite volatile through the 1980s. The high money growth rate is higher for the 1994 sample period compared to the 2000 sample (compare Tables 1 and 2). As well, for the 1994 sample, it is the high money growth regime that is associated with low monetary control errors. For the 1994 sample parameters, the lower and more volatile money growth rates in the 1980s are more likely to have been generated by the low money growth regime. Consequently, beliefs rapidly converge to the low money growth regime.

Now, consider the parameter estimates for the 2000 sample. The lower average money growth rates in the 1980s would tend to move beliefs towards the low money growth regime. However, the greater volatility is more likely to have occurred under the high money growth regime. Further, the

¹⁴Given that the model abstracts from all other types of shocks, predicted behavior is perhaps better interpreted as a deviation from what would have happened in the absence of money shocks.

difference in the mean money growth rates across regimes is smaller for this parameterization. The net result is that beliefs switch away from the high money growth regime only late in the 1980s.

7 Conclusion

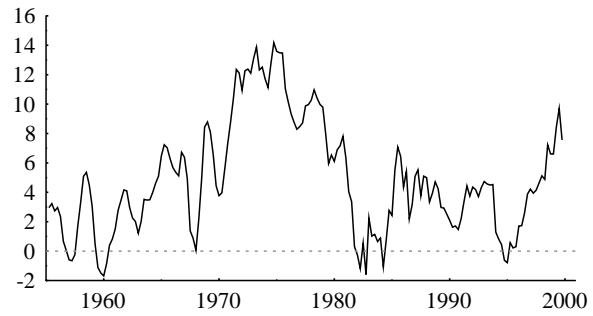
This paper has examined the properties of a dynamic general equilibrium model that features stochastic shifts in monetary policy regimes under alternative information structures reflecting two extreme views on policy credibility. For empirically plausible parameter values describing the structure of the economy, it was demonstrated how the implementation of a credible disinflation policy resulted in a rapid expansion of output together with lower rates of interest. In contrast, a noncredible disinflation policy resulted in a short-lived recession together with persistently higher rates of interest. In this latter case, inflation expectations were shown to evolve sluggishly, with (rational) inflation forecasts persistently exceeding actual inflation along the transition path.

Conditional on our parameterization of the data generating process for monetary policy, we estimated that the change in monetary policy that seemed to occur in Canada some time in the late 1970s or early 1980s took a long time (virtually a decade) before it was firmly believed to have happened by the general public. Confidence in the tight-money regime seems to have been repressed owing to the volatile nature of money growth over the 1980s (a property that appears to be more likely associated with loose-money policies). We calculate that expectations of inflation (and nominal interest rates) would have averaged two percentage points lower – and the level of real output half a percent higher – throughout most of the 1980s had the disinflation policy been fully credible. These conclusions are based on the parameter estimates for the sample ending in 2000:4. For the 1994 sample period parameters, individuals infer that monetary policy switched to low money growth much earlier, and consequently noncredibility of monetary policy is confined to the early 1980s.

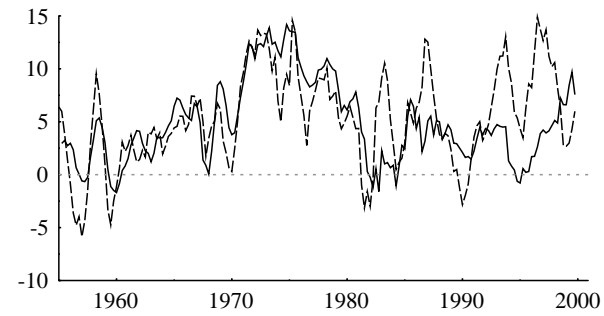
The main point of this paper is that uncertainty over monetary policy regimes can propagate the liquidity effect associate with exogenous regime changes. While the analysis above contains more than its fair share of abstraction, none of this is likely to significantly affect the main message of the paper, although obviously details and quantitative implications might differ. One criticism that has been leveled at the framework here concerns the specification of monetary policy; i.e., in the model, money growth is completely exogenous while in reality it seems to respond to the state of the economy. This observation is likely more relevant for what we have termed ‘monetary control errors’ and one could easily imagine embedding a policy reaction function around each of the exogenous regimes. As far as modeling the regimes themselves, we believe that it is appropriate to treat these as exogenous, since they are likely determined by forces that are beyond the scope of most conventional economic models, like fiscal shocks or changes in the central bank’s objective function.

References

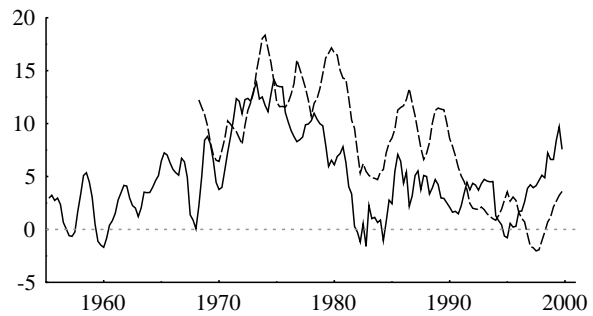
- CHRISTIANO, L. J., "Modeling the Liquidity Effect of a Money Shock," *Federal Reserve Bank of Minneapolis Quarterly Review* 3–34.
- CHRISTIANO, L. J. AND M. EICHENBAUM, "Liquidity Effects and the Monetary Transmission Mechanism," *American Economic Review* 82 (1992), 346–353.
- CHRISTIANO, L. J. AND C. GUST, "The Expectations Trap Hypothesis," in K. Clinton and W. Engert, (eds.) "Money, Monetary Policy, and Transmission Mechanisms," (Ottawa, Canada: Bank of Canada) (2000) 347–383.
- COLEMAN, W. J., II, "Equilibrium in a Production Economy with an Income Tax," *Econometrica* 59 (1991), 1091.
- COOK, D., "The Liquidity Effect and Money Demand," *Journal of Monetary Economics* 43 (1999), 377–390.
- COOLEY, T. F. AND G. D. HANSEN, "The Inflation Tax in a Real Business Cycle Model," *American Economic Review* 79 (1989), 733–48.
- COOLEY, T. F. AND V. QUADRINI, "A Neoclassical Model of the Phillips Curve Relation," *Journal of Monetary Economics* 44 (1999), 165–193.
- CUKIERMAN, A. AND A. H. MELTZER, "A Theory of Ambiguity, Credibility, and Inflation Under Discretion and Asymmetric Information," *Econometrica* 54 (1986), 1099–1128.
- DOTSEY, M. AND J. L. DEVARO, "Was the Disinflation of the Early 1980s Anticipated?" *Federal Reserve Bank of Richmond Economic Quarterly* 81 (1995), 41–59.
- FUERST, T. S., "Liquidity, Loanable Funds, and Real Activity," *Journal of Monetary Economics* 29 (1992), 3–24.
- HAMILTON, J. D., "A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle," *Econometrica* 57 (1989), 357–84.
- LUCAS, R. E., JR., "Liquidity and Interest Rates," *Journal of Economic Theory* 50 (1990), 237–264.
- PRESCOTT, E. C., "Theory Ahead of Business Cycle Measurement," *Federal Reserve Bank of Minneapolis Quarterly Review* 10 (1986), 9–22.
- RICKETTS, N. AND D. ROSE, "Inflation, Learning and Monetary Policy Regimes in the G-7 Countries," Working Paper 95–6, Bank of Canada (1995).
- ROMER, C. D. AND D. H. ROMER, "Does Monetary Policy Matter? A New Test in the Spirit of Friedman and Schwartz," in O. J. Blanchard and S. Fischer, (eds.) "NBER Macroeconomics Annual," (Cambridge, Mass. and London: MIT Press) (1989) 121–170.
- THOMAS, L. B., JR., "Survey Measures of Expected U.S. Inflation," *Journal of Economic Perspectives* 13 (1999), 125–144.



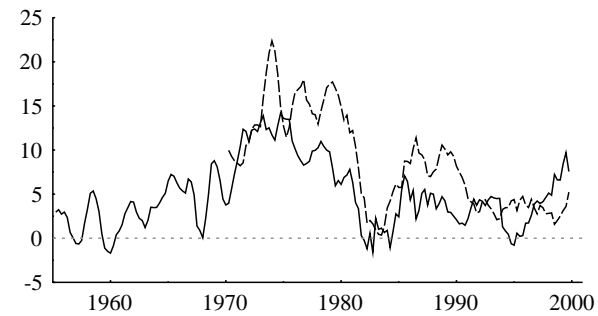
(a) Money Base Growth



(b) Money Base (solid) and M1 (dashed)



(c) Money Base (solid) and M2 (dashed)



(d) Money Base (solid) and M3 (dashed)

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.

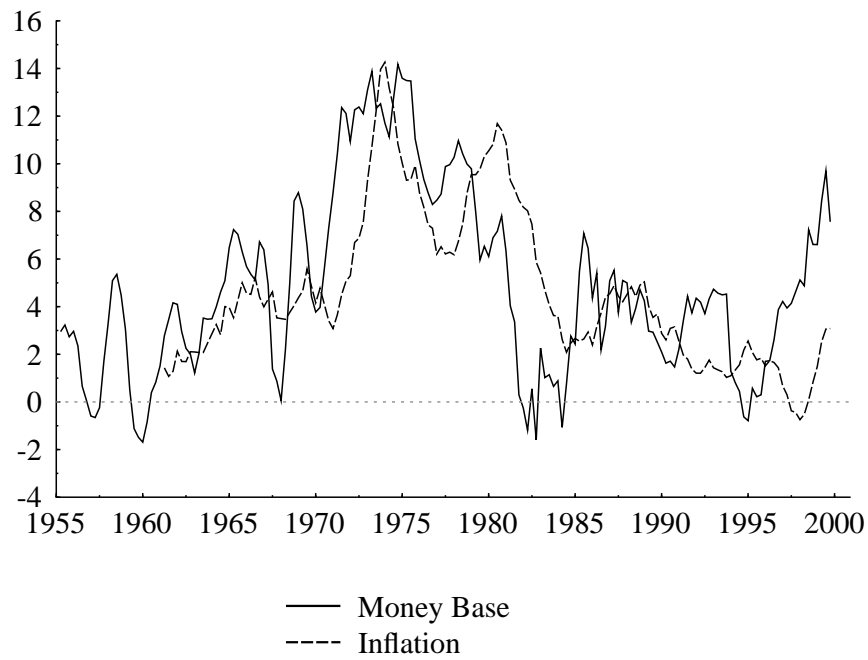


Figure 2: CANSIM Label: D15612 (GDP Deflator). Quarterly rates of change in the price level have been annualized and smoothed with a five-quarter moving average.

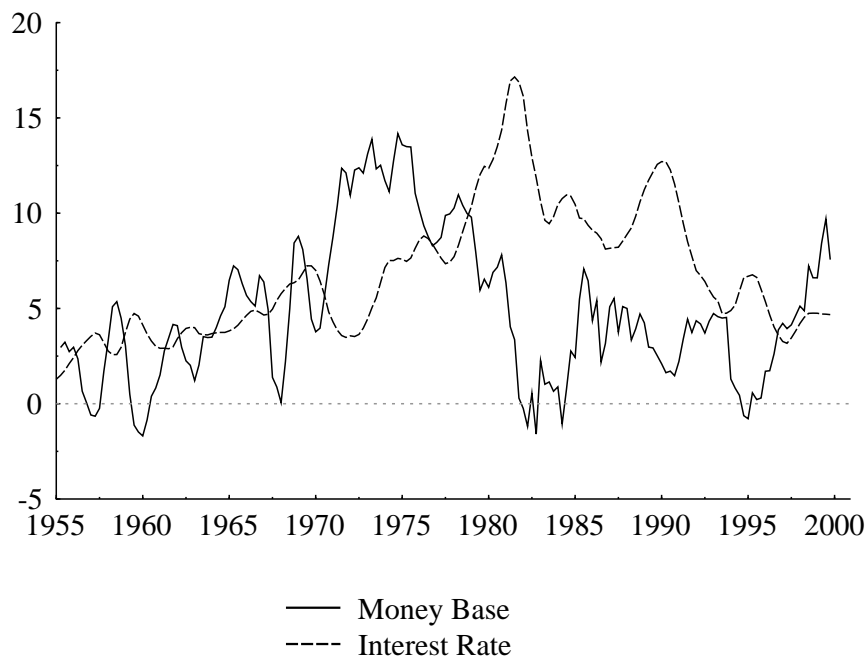


Figure 3: CANSIM Label: B14001 (91 Day Government Treasury Bill Rate, Annualized).

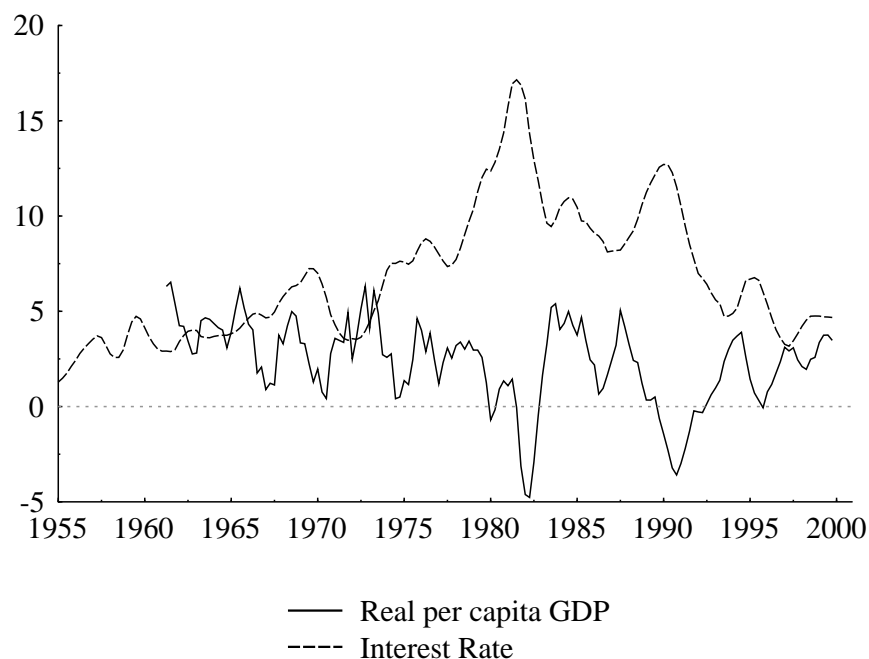


Figure 4: CANSIM Label: D14872 (Real GDP). The output measure has been deflated by the population; quarterly growth rates have been annualized and smoothed with a five-quarter moving average.

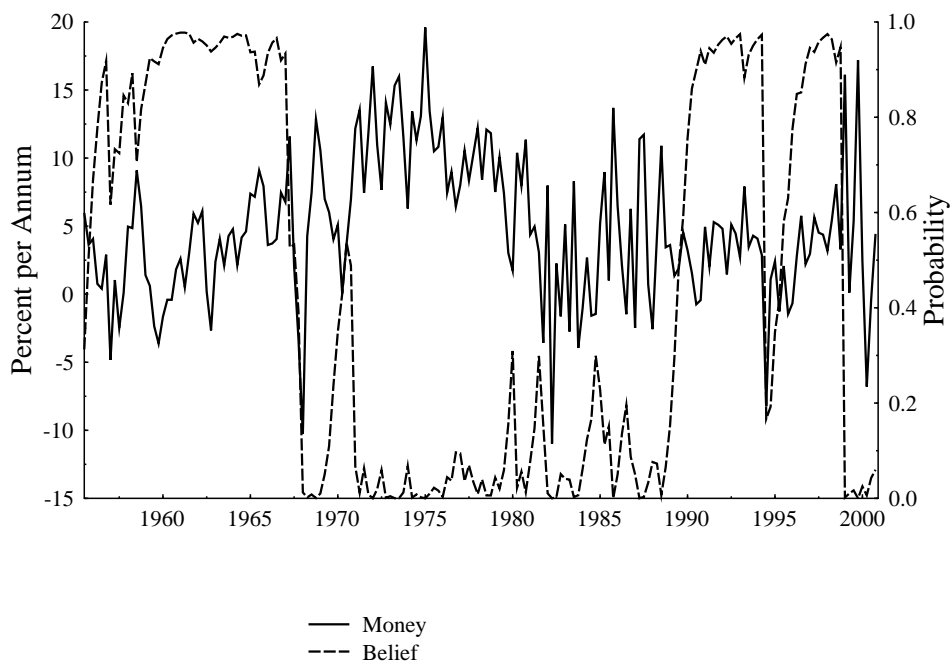
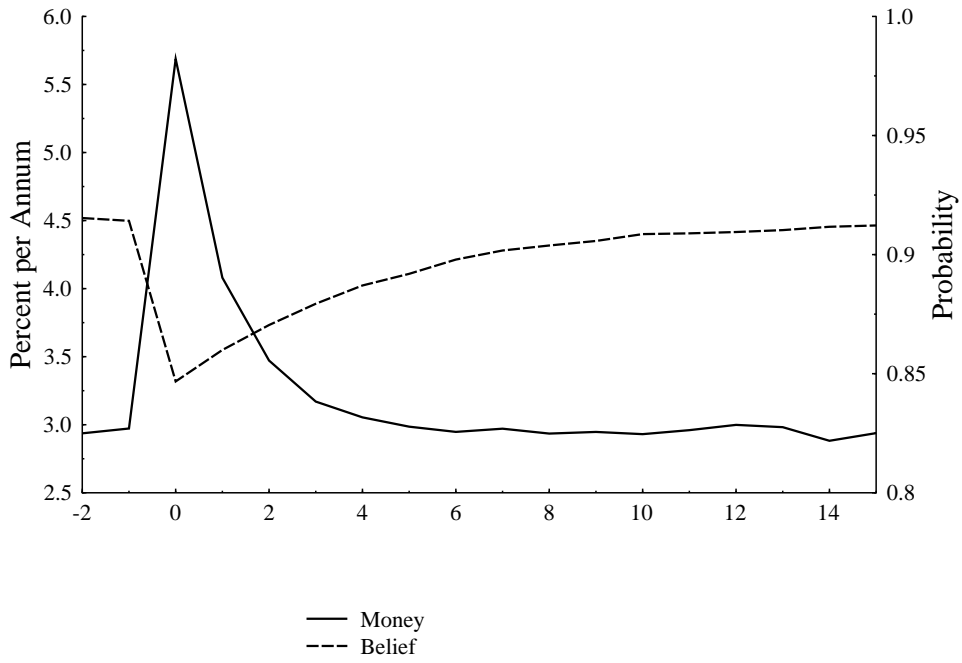
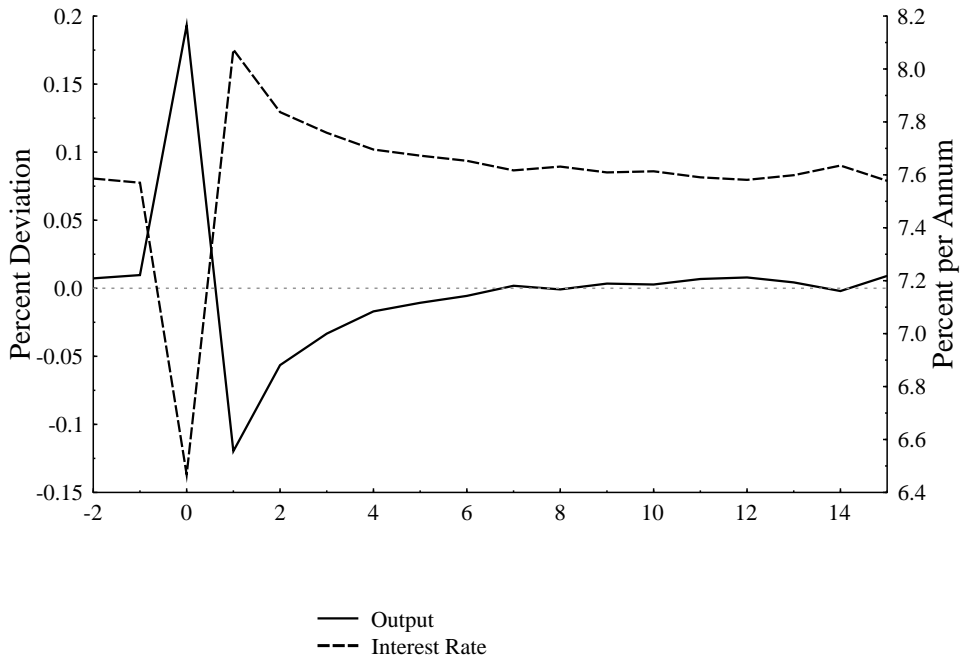


Figure 5: The growth rate in the monetary base is as described in Figure 1 (without smoothing). The initial belief was set to its unconditional mean.

Figure 6: Transitory Money Shock

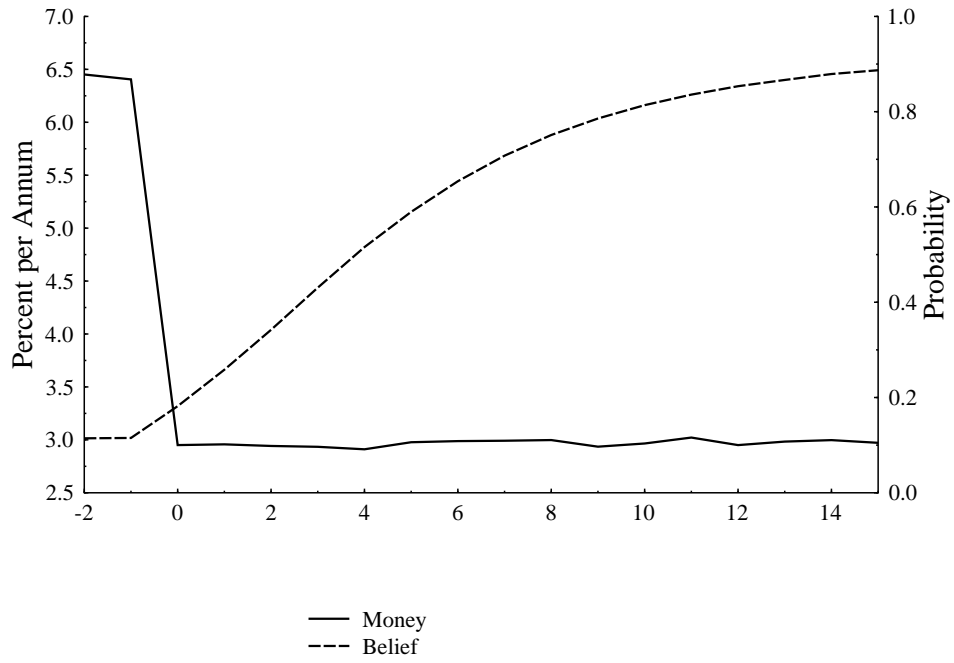


(a) Money Growth and Belief

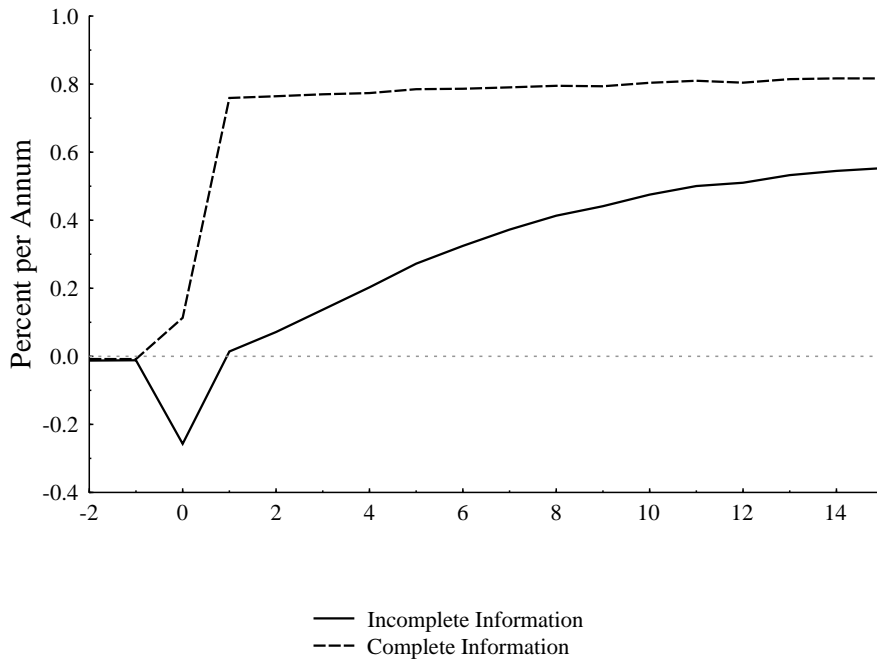


(b) Output and the Interest Rate

Figure 7: Disinflation Policy

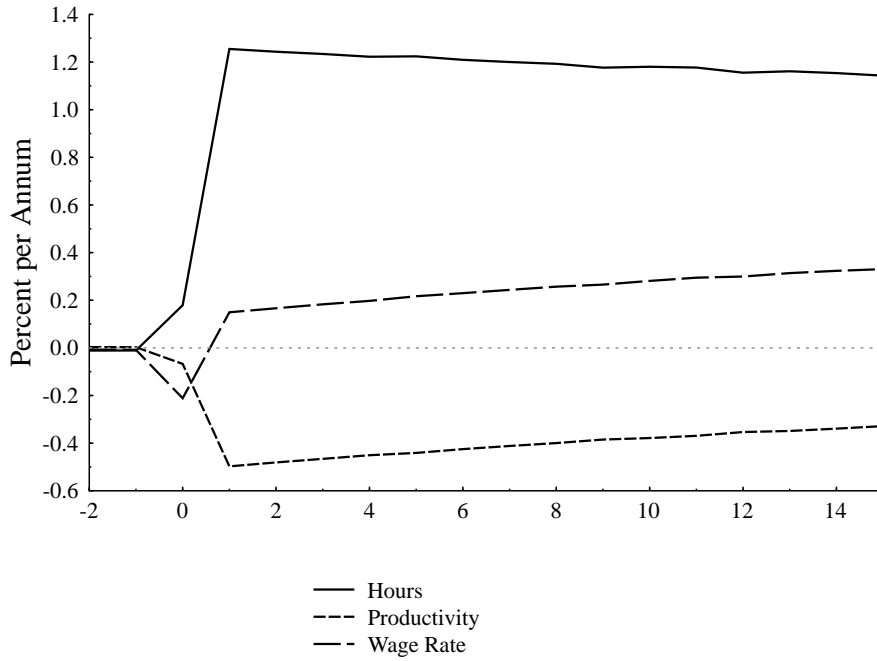


(a) Money Growth and Belief

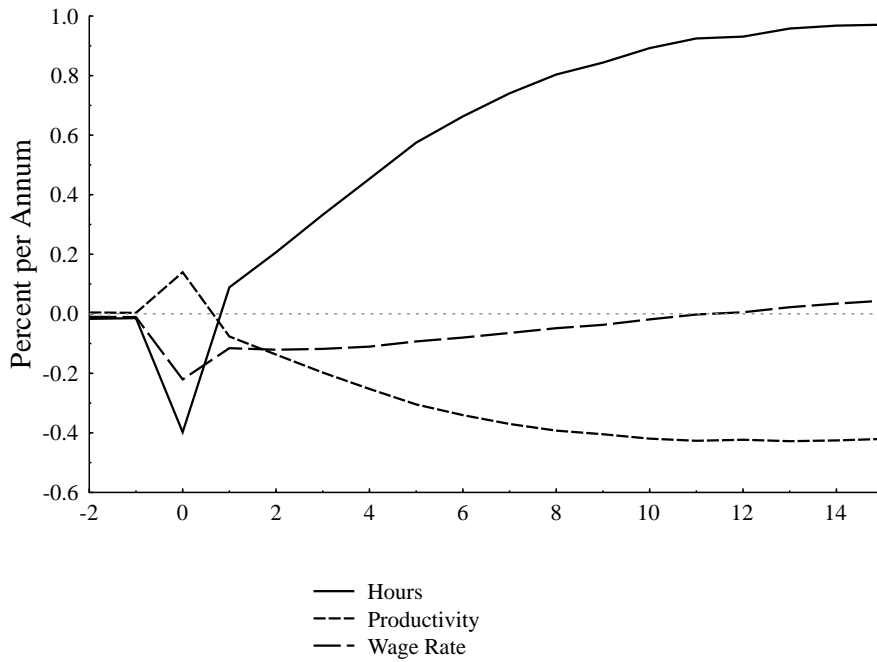


(b) Output

Figure 8: Disinflation Policy

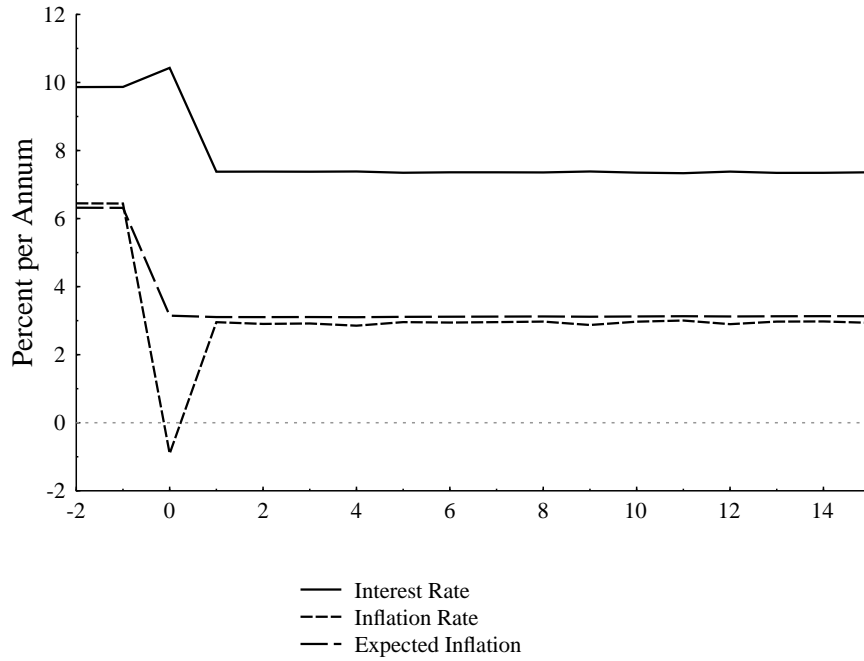


(a) Complete Information

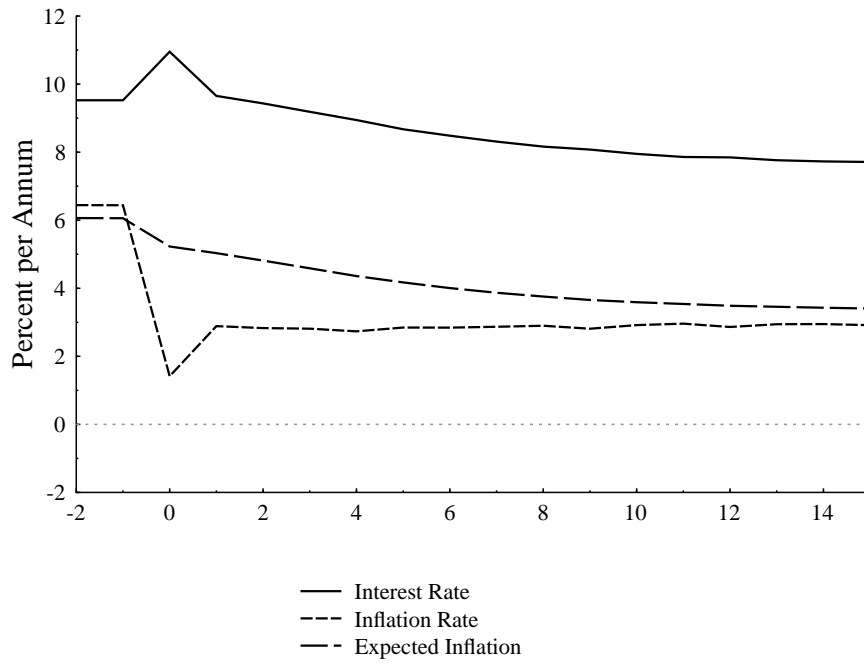


(b) Incomplete Information

Figure 9: Disinflation Policy



(a) Complete Information



(b) Incomplete Information

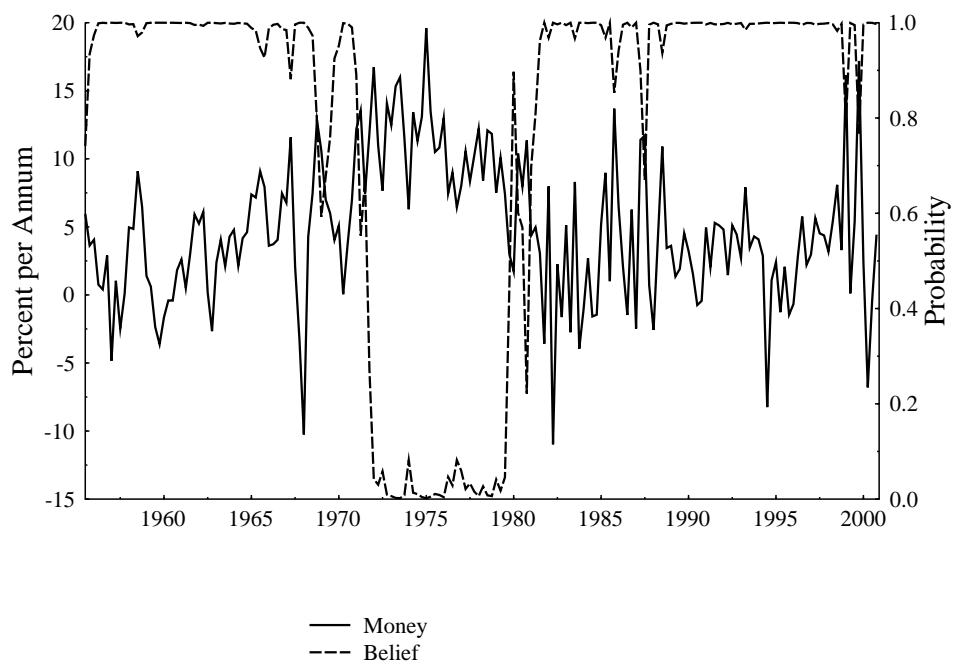
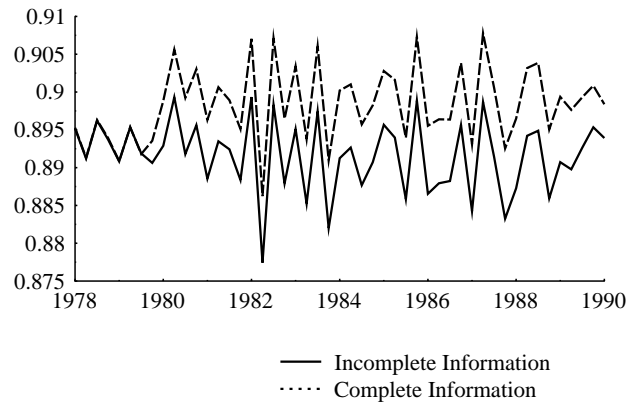
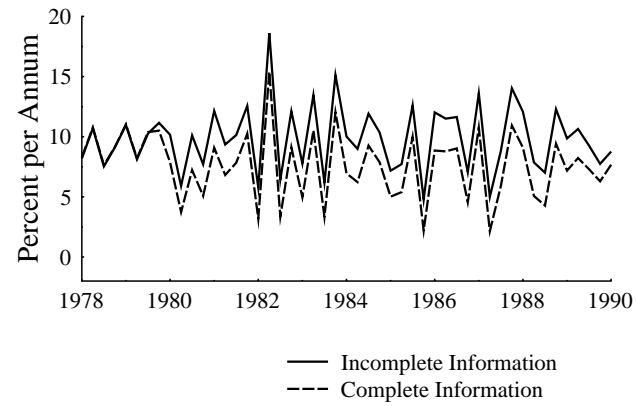


Figure 10: The growth rate in the monetary base is as described in Figure 1 (without smoothing). The initial belief was set to its unconditional mean.

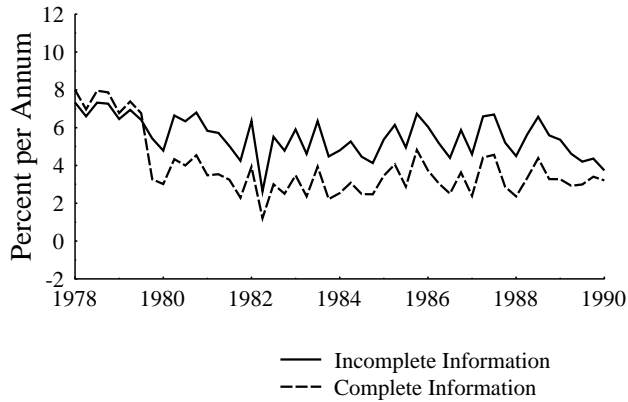
Figure 11: Actual Regime Change in 1979:4 – 2000 Parameter Estimates



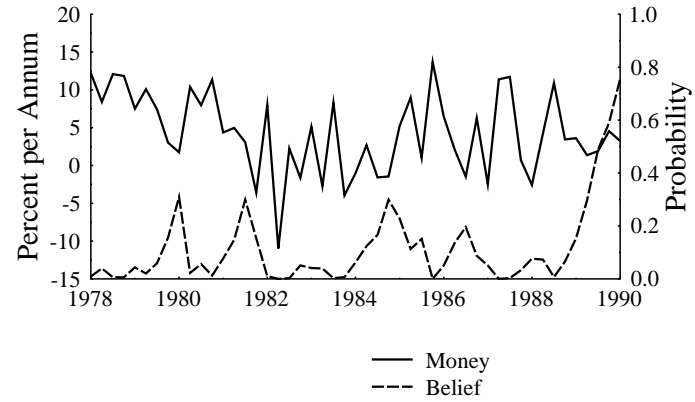
(a) Output



(b) Nominal Interest Rate

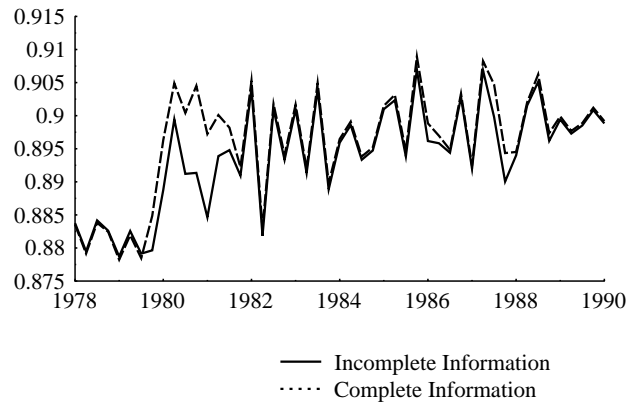


(c) Expected Inflation

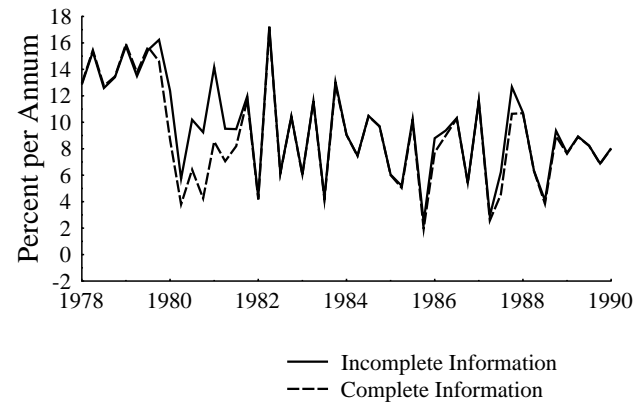


(d) Money Growth and Belief

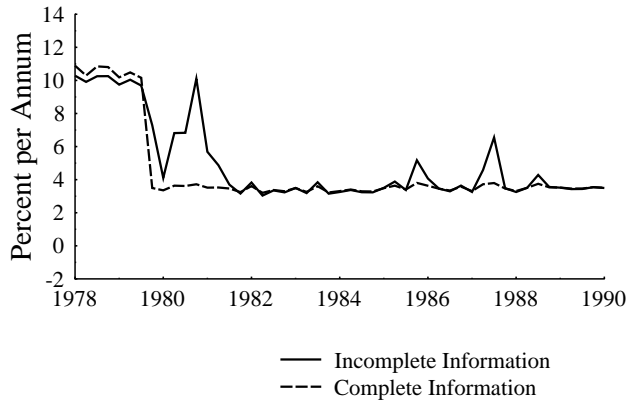
Figure 12: Actual Regime Change in 1979:4 – 1994 Parameter Estimates



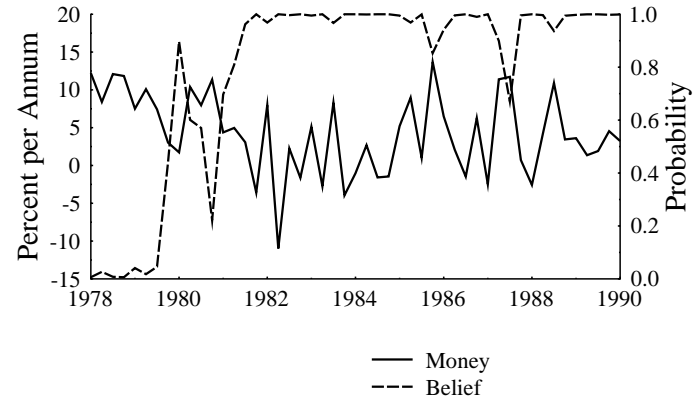
(a) Output



(b) Nominal Interest Rate



(c) Expected Inflation



(d) Money Growth and Belief

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