Federal Reserve Credibility and Inflation Scares

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We develop a simple, quantitative model of the U.S. economy to demonstrate how an "inflation scare" may occur when the Federal Reserve lacks full credibility. In particular, we show that the long-term nominal interest rate may undergo a sudden increase if an adverse movement in the inflation rate triggers a deterioration in the public's beliefs about the Federal Reserve's commitment to maintaining low inflation in the future. We find that simulations from our model capture some observed patterns of U.S. interest rates in the 1980s.

After two decades of rising inflation during the 1960s and 1970s, the Federal Reserve under Chairman Paul Volcker undertook a deliberate disinflationary policy that was successful in reducing the U.S. inflation rate from well over 10 percent in 1980 to around 3 percent by 1985. The cost of this victory, however, was an extremely severe recession: the civilian unemployment rate peaked at about 11 percent in 1982—the highest level observed in the U.S. economy since the Great Depression.

It is widely recognized that an important factor governing the cost of disinflationary policies is the degree of central bank credibility.[1] Credibility is important because it influences the public's expectations about future inflation.[2] These expectations, in turn, affect the *current* state of the economy because they are incorporated into wages via forward-looking labor contracts and into the level of long-term nominal interest rates, which govern borrowing behavior. When the central bank enjoys a high degree of credibility, rational agents will quickly lower their inflation expectations in response to an announced policy to reduce the prevailing rate of inflation. This shift in expectations helps to lower current inflation, leading to a faster and less costly disinflation episode. In contrast, when central bank credibility is low, agents' expectations respond only gradually as they become convinced of the central bank's commitment to reducing inflation. In such an environment, nominal wages and long-term interest rates adjust slowly to the new inflation regime, contributing to a misallocation of resources and a more costly transition to low inflation.

The above reasoning suggests that low credibility on the part of the Federal Reserve may help to explain the severity of the recession induced by the Volcker disinflation. Indeed, it seems likely that the Federal Reserve's commitment to reducing inflation was viewed with considerable skepticism in 1980. Two previous attempts to reduce inflation begun in April 1974 and August 1978 had

1. See, for example, Sargent (1982, 1983), Taylor (1982), and Fischer (1986).

2. This idea is the basis for many game theoretic models of credibility in monetary policy. See, for example, Barro and Gordon (1983), Backus and Driffill (1985a,b), Barro (1986), and Cukierman and Meltzer (1986). For an excellent survey of this literature, see Blackburn and Christensen (1989).

proven unsuccessful.[3] Contributing to this skepticism in the early stages of the disinflation were large and erratic fluctuations of monetary aggregates, which were frequently outside their target ranges.[4] Moreover, U.S. fiscal policy during the early 1980s was characterized by large and growing federal budget deficits which, if projected forward, might have been seen to imply the need for future monetization of the debt to maintain solvency of the government's intertemporal budget constraint.[5]

In this paper, we develop a simple, quantitative model of the U.S. economy to demonstrate how imperfect credibility on the part of the Federal Reserve may give rise to an episode known as an "inflation scare." Following Goodfriend (1993), we define an inflation scare as a significant increase in the long-term nominal interest rate that takes place in the absence of any aggressive tightening by the Fed that would serve to push up short-term rates. Hence, during an inflation scare, the increase in the long rate is driven primarily by an upward shift in agents' expectations about future inflation. In our model of an inflation scare, an adverse movement in the inflation rate triggers a deterioration in the public's beliefs about the Federal Reserve's commitment to maintaining low inflation in the future. This leads to a sudden increase in the long-term nominal interest rate, even while the short-term rate can actually be falling. We find that simulations from our model capture some observed patterns of U.S. interest rates in the 1980s.

The framework for our analysis is a version of the rational expectations macroeconomic model developed by Fuhrer and Moore (1995a,b). This model is quite tractable and has the advantage of being able to reproduce the dynamic correlations among U.S. inflation, short-term nominal interest rates, and deviations of real output from trend. The model consists of an aggregate demand equation, a nominal wage contracting equation (that embeds a version of an expectations-augmented Phillips curve), a Fed reaction function that defines monetary policy, and a term structure equation. A simple version of Okun's law relates the unemployment rate to the deviation of real output from trend.

We consider an experiment where the economy is initially in a regime of high and variable inflation and the Fed announces a program to reduce both the mean and variance of the inflation rate. The announced program (which is immediately implemented) involves a change to the parameters of the reaction function. Specifically, the inflation target is lowered and more weight is placed on minimizing the variance of inflation versus stabilizing output. We formalize the notion of credibility as the public's subjective probabilistic belief that the reaction function parameters have in fact been changed. The true parameters are assumed to be unobservable due to the presence of exogenous stochastic shocks that enter the reaction function. These policy shocks, together with stochastic disturbances to other parts of the economy, give rise to a distribution of observed inflation rates around any given inflation target.

Under full credibility, the economy is assumed to be populated by agents who, upon hearing the Fed's announcement, assign a probability of one to the event that the reaction function has changed. These agents continue to assign a probability of one regardless of the time path of inflation that is subsequently observed. In contrast, partial credibility implies that agents update their prior assessment of the true reaction function in a (quasi) Bayesian way on the basis of the Fed's success or failure in reducing inflation over time. Our setup is similar to one used by Meyer and Webster (1982) in which agents' expectations are constructed as a probability weighted average of the expectations that would prevail under an "old" and "new" policy rule.[6]

The behavior of the long-term nominal interest rate in the model is governed by the pure expectations hypothesis, that is, the long-term rate is a weighted average of current and expected future short-term rates. If the short rate rises as a result of tighter monetary policy, the implications for the long rate are theoretically ambiguous. In particular, upward pressure stemming from the increase in the current short rate may be offset by downward pressure from the anticipation of lower short rates in the future, due to lower expected inflation. Thus, by affecting the level of expected inflation, the degree of Fed credibility can exert a strong influence on the long-term nominal interest rate.

Using reaction function parameters estimated over the two sample periods 1965:1 to 1979:4 and 1980:1 to 1996:4 we trace out the economy's dynamic transition path for the

3. See Shapiro (1994) for an analysis of the relative success of Federal Reserve attempts to reduce inflation following seven postwar dates marking the start of an explicit disinflationary policy, as identified by Romer and Romer (1989, 1994).

4. For details on monetary policy in the early 1980s, see Friedman (1984), Blanchard (1984), Hetzel (1986), and Goodfriend (1993, 1997).

5. The crucial importance of the fiscal regime in determining the credibility of disinflationary policies is emphasized by Sargent (1982, 1983, 1986). For applications of this idea, see Flood and Garber (1980) and Ruge-Murcia (1995).

6. Other research that applies Bayesian learning to models of monetary policy includes Taylor (1975), Flood and Garber (1980), Backus and Driffill (1985a,b), Barro (1986), Lewis (1989), Baxter (1989), Bertocchi and Spagat (1993), Gagnon (1997), and Andolfatto and Gomme (1997). For related models with least squares learning, see Friedman (1979), Fuhrer and Hooker (1993), and Sargent (1998).

two specifications of credibility described above. The speed at which agents adjust their inflation expectations in response to the change in monetary policy depends crucially on the Fed's credibility: expectations adjust quickly with full credibility and slowly with partial credibility.

Under both specifications of credibility, we find that the inflation rate exhibits damped oscillations as the economy transitions to the new stationary equilibrium. Following the change in Fed policy, the inflation rate undergoes an initial drop, but ends up overshooting the new target level. The inflation rate then starts to increase as it approaches the new target from below. When the Fed does not have full credibility, agents interpret this interval of rising inflation as evidence that monetary policy has not in fact changed and therefore will continue to tolerate an environment of high and variable inflation. Consequently, agents' expectations of future inflation are revised upward, and the long-term nominal interest rate experiences a sudden increase. In this way, our model generates an endogenous inflation scare.

Numerical simulations of our model produce a 2 percentage point jump in the long-term nominal interest rate that begins about 24 quarters after the change in Fed policy. A similar pattern can be observed in the U.S. data about 29 quarters after the start of the Volcker disinflation.[7] Specifically, from 1986:4 to 1987:4, the yield on a 10-year Treasury bond increased sharply, despite only a small increase in the 3-month Treasury bill rate. Over this same period, the inflation rate (based on the GDP deflator) was rising. This pattern suggests that the increase in the U.S. long rate was driven by an upward shift in the public's expectations about future inflation, thus conforming with our definition of an inflation scare. Given this interpretation of the data, the 1987 scare episode illustrates the long memory of the public in recalling the high and variable inflation of the 1970s, and serves as an important reminder of the fragility of Federal Reserve credibility.

Although Goodfriend (1993) identifies three other inflation scare episodes in U.S. data that occurred much closer to the start of the Volcker disinflation,[8] we choose to emphasize the 1987 scare for two reasons: First, the magnitude and timing of the 1987 episode is reasonably close to the inflation scare that we are able to generate using the model, and second, the episode stands out readily in a plot of quarterly U.S. data. Interestingly, the 1987 scare occurred shortly after U.S. inflation "bottomed out" and again started to rise. This feature of the data resembles the dynamic overshooting behavior of inflation in our model. The point of the exercise, however, is simply to illustrate the mechanics by which an inflation scare may occur—not to identify any one episode as being more significant than the others.

The remainder of the paper is organized as follows. Section I describes the model and our specification of Federal Reserve credibility. Section II presents our parameter estimates and examines their sensitivity to different sample periods. Section III presents our simulation results. Section IV concludes.

I. THE MODEL

The model is a version of the one developed by Fuhrer and Moore (1995a,b). This framework has the advantage of being able to reproduce the pattern of dynamic correlations exhibited by an unconstrained vector autoregression system involving U.S. inflation, short-term nominal interest rates, and deviations of real output from trend. In the model, agents' expectations are rational and take into account the nature of the monetary policy regime, as summarized by the parameters of the Fed reaction function. However, since the other parts of the economy are specified as reduced-form equations, the model is susceptible to Lucas's (1976) econometric policy critique. Our estimation procedure attempts to gauge the quantitative importance of the Lucas critique for our results by examining the stability of the model's reduced form parameters across different sample periods. The equations that describe the model are as follows:

Aggregate Demand / I-S Curve

$$\tilde{y}_t = a_1\tilde{y}_{t-1} + a_2\tilde{y}_{t-2} + a_\rho(\rho_{t-1} - \bar{\rho}) + \varepsilon_{yt}, \tag{1}$$

where $\tilde{y}_t$ is the so-called "output gap" defined as the deviation of log per-capita real output from trend and ρ_{t-1} is the lagged value of the ex ante long-term real interest rate. The error term $\varepsilon_{yt} \sim N(0, \sigma^2_{\varepsilon y})$ captures random fluctuations in aggregate demand. We assume that the steady-state value of $\tilde{y}_t$ is zero, which implies that $\bar{\rho}$ is the steady-state real interest rate.

7. We take the starting date of the Volcker disinflation to be October 6, 1979, which coincides with Fed's announcement of a new operating procedure for targeting nonborrowed reserves. This starting date is consistent with the findings of Romer and Romer (1989), who use evidence from the minutes of Federal Open Market Committee meetings to identify October 1979 as a date when the Federal Reserve decided to undertake an explicit disinflationary policy.

8. The approximate dates of these episodes are: (1) December 1979 to February 1980, (2) December 1980 to October 1981, and (3) May 1983 to June 1984.

Wage Contracting Specification / Short-Run Phillips Curve

$$(2)\qquad \pi_t = \tfrac{1}{2}(\pi_{t-1} + E_t\pi_{t+1}) + \tfrac{\gamma}{2}(\tilde{y}_t + \tilde{y}_{t-1}) + \varepsilon_{\pi t},$$

where π_t is the inflation rate defined as the log-difference of the price level, E_t is the expectation operator conditional on information available at time t, and $\varepsilon_{\pi t} \sim N(0, \sigma^2_{\varepsilon\pi})$ is an error term. Fuhrer and Moore (1995a) show that (2) can be derived from a two-period model of staggered nominal wage contracts, where the real value of the contract price negotiated at time t is a simple average of the real contract price negotiated at $t-1$ and the real contract price that agents expect to negotiate at $t+1$, adjusted for the level of aggregate demand. The forward-looking nature of wage contracts creates an environment where current inflation depends on expected inflation. The error term represents a stochastic disturbance that affects labor supply decisions.[9]

Equation (2) can also be interpreted as a version of an expectations-augmented Phillips curve.[10] Evidence of a short-term Phillips curve trade-off can be found in the positive correlation between inflation and the real output gap in postwar U.S. data, and the corresponding negative correlation between inflation and the unemployment rate.[11] The steady-state version of (2) implies that there is no long-run trade-off between inflation and real output.

Federal Reserve Reaction Function

$$(3)\qquad r_t = r_{t-1} + \alpha_\pi(\pi_t - \bar{\pi}) + \alpha_y\tilde{y}_t + \varepsilon_{rt},$$

where r_t is the short-term nominal interest rate $\bar{\pi}$ is the inflation target, and $\varepsilon_{rt} \sim N(0, \sigma^2_{\varepsilon r})$ is an exogenous stochastic shock that is not directly observed by the public. The policy rule implies that the Fed strives to smooth short-term interest rates, but responds to deviations of inflation from target and to deviations of output from trend. The strength of the interest rate response to these deviations is governed by the parameters α_π and α_y.[12] We interpret ε_{rt} as capturing random, nonsystematic factors that arise from the political process or the interaction of policymakers with different preferences, different target rates of inflation, etc. Alternatively, we could interpret ε_{rt} as reflecting operational or institutional features that preclude perfect control of r_t.[13] The presence of the unobservable shock term is crucial for our credibility analysis because it prevents agents from being able to quickly learn the true values of $\bar{\pi}$, α_π, and α_y from a sequence of four observations on r_t, π_t, and $\tilde{y}_t$. Equation (3) implies that the steady-state inflation rate is $\bar{\pi}$.

Real Term Structure

$$(4)\qquad \rho_t - D(E_t\rho_{t+1} - \rho_t) = r_t - E_t\pi_{t+1},$$

where D is the duration of a real consol that is used here to approximate a finite maturity long-term bond. Equation (4) is an arbitrage condition that equates the expected real holding-period return on a long-term bond (interest plus capital gains) with the expected real yield on a short-term Treasury security. In steady-state, (4) implies the Fisher relationship: $\bar{r} = \bar{\rho} + \bar{\pi}$. By repeatedly iterating (4) forward and solving the resulting series of equations for ρ_t, we obtain the following expression:

$$(5)\qquad \rho_t = \tfrac{1}{1+D}E_t\sum_{i=0}^{\infty}\left(\tfrac{D}{1+D}\right)^i(r_{t+i} - \pi_{t+1+i}),$$

which shows that the ex ante long-term real rate is a weighted average of current and expected future short-term real rates.[14]

Nominal Term Structure

$$(6)\qquad R_t - D(E_tR_{t+1} - R_t) = r_t,$$

$$(7)\qquad R_t = \tfrac{1}{1+D}E_t\sum_{i=0}^{\infty}\left(\tfrac{D}{1+D}\right)^i r_{t+i},$$

where R_t is the nominal yield on the long-term bond. The above equations are the nominal counterparts of (4) and (5). In steady-state, equation (6) implies $\bar{R} = \bar{r}$.

Okun's Law

$$(8)\qquad u_t = (1 - b_1)\bar{u} + b_1u_{t-1} + b_2\tilde{y}_t + b_3\tilde{y}_{t-1} + b_4\tilde{y}_{t-2} + \varepsilon_{ut},$$

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9. We do not explicitly link the supply shock $\varepsilon_{\pi t}$ to the real price of oil. Fuhrer and Moore (1995a, footnote 15) report that oil prices are uncorrelated with the residuals of their contracting equation, suggesting that their omission does not affect the model's performance. See Bernanke, Gertler, and Watson (1997) for an empirical study of the potential links between oil prices and monetary policy.

10. See Roberts (1997).

11. King and Watson (1994) document the robust negative correlation between inflation and unemployment at business cycle frequencies.

12. The policy rule is similar to one proposed by Taylor (1993), which takes the form: $r_t = (\bar{\rho} + \pi_t) + \alpha_\pi(\pi_t - \bar{\pi}) + \alpha_y\tilde{y}_t$, where $\bar{\rho}$ is the steady-state real interest rate. The Taylor rule uses $\bar{\rho} = 0.02$, $\alpha_\pi = \alpha_y = 0.5$, and $\bar{\pi} = 0.02$. See Taylor (1998) and Judd and Rudebusch (1998) for historical analyses of how policy rules of this form fit U.S. interest rate data.

13. Cukierman and Meltzer (1986) develop a model in which the central bank intentionally adopts an imprecise monetary control process in order to obscure its preferences, and thereby exploit a more favorable output-inflation trade-off.

14. In going from (4) to (5) we have applied the law of iterated mathematical expectations.

where u_t is the unemployment rate, $\bar{u}$ is the corresponding steady-state, and $\varepsilon_{ut} \sim N(0, \sigma^2_{\varepsilon u})$ is an error term.[15]

Credibility

In modeling the role of credibility during the Volcker disinflation, we abstract from the Fed's adoption of a new operating procedure for targeting nonborrowed reserves from October 1979 to October 1982. Studies by Cook (1989) and Goodfriend (1993) indicate that the majority of federal funds rate movements during this period were the result of deliberate, judgmental policy actions by the Fed, and not automatic responses to deviations of the money stock from its short-run target.[16] Moreover, it has been suggested that the Fed's emphasis on monetary aggregates during this period was simply a device that allowed it to disclaim responsibility for pushing up short-term nominal interest rates to levels that would otherwise have been politically infeasible. Based on the above reasoning, we interpret the Fed's statement on October 6, 1979, as an announcement of a change in the parameters of the reaction function.[17]

We consider an experiment where the economy is initially in a regime of high and variable inflation and the Fed announces a program to reduce both the mean and variance of the inflation rate. The announced program (which is immediately implemented) involves a change to the parameters of the reaction function (3). Specifically, the inflation target $\bar{\pi}$ is lowered, the parameter α_π is increased, and the parameter α_y is decreased. This constitutes a regime shift that is consistent with the empirical evidence of a statistical break in U.S. inflation occurring around October 1979.[18] The increase in α_π relative to α_y implies a decision on the part of the Fed to place more emphasis on minimizing the variance of inflation and less emphasis on stabilizing output.[19] It is important to recognize that we have simply posited the Fed's decision to change monetary policy, since our model abstracts from any economic benefits of low and stable inflation. Moreover, we do not attempt to explain how the Fed allowed inflation to become too high and variable in the first place.[20]

We define credibility as the public's subjective probabilistic belief that the announced policy change has in fact occurred. To formalize this idea, we endow agents with the knowledge of two possible reaction functions and the corresponding equilibrium distributions of π_t that arise under each. The two reaction functions are defined by the parameter combinations $\{\bar{\pi}^H, \alpha^H_\pi, \alpha^H_y\}$ and $\{\bar{\pi}^L, \alpha^L_\pi, \alpha^L_y\}$, where $\bar{\pi}^L < \bar{\pi}^H$, $\alpha^L_\pi > \alpha^H_\pi$, and $\alpha^L_y < \alpha^H_y$. In a stationary equilibrium, the linearity of the model, together with the assumptions that ε_{yt}, $\varepsilon_{\pi t}$, and ε_{rt} are i.i.d. normal implies

$$\pi_t \sim N(\bar{\pi}, \sigma^2_\pi), \tag{9}$$

where the mean of the inflation distribution is the steady-state and the variance σ^2_π depends on the variances of the stochastic shocks.

We assume that the economy is initially in a stationary equilibrium with the reaction function parameters $\{\bar{\pi}^H, \alpha^H_\pi, \alpha^H_y\}$. These parameters give rise to the distribution $\pi_t \sim N(\bar{\pi}^H, \sigma^2_{\pi H})$. At $t = t^*$ the Fed adopts the new reaction function parameters $\{\bar{\pi}^L, \alpha^L_\pi, \alpha^L_y\}$ and announces this action to the public. The unobservable error term ε_{rt} in (3) prevents the public from being able to verify the Fed's announcement from a sequence of four observations of r_t, π_t, and $\tilde{y}_t$. Hence, the public's beliefs regarding the reaction function parameters are used to form expectations while the true parameter values are used in (3) to compute the period-by-period values of r_t. Learning takes place (as described below), and the economy eventually converges to a new stationary equilibrium with $\pi_t \sim N(\bar{\pi}^L, \sigma^2_{\pi L})$, where $\sigma^2_{\pi L} < \sigma^2_{\pi H}$. In other words, the change in Fed policy ultimately brings about an inflation distribution with a lower mean and a lower variance.

We consider two specifications of credibility, labeled "full" and "partial." Full credibility implies that agents assign the probability $p_t = 1$ to the parameter combination $\{\bar{\pi}^L, \alpha^L_\pi, \alpha^L_y\}$ for all $t \geq t^*$. Under partial credibility, agents assign a "prior" probability to the parameter combination $\{\bar{\pi}^L, \alpha^L_\pi, \alpha^L_y\}$ at the time of the Fed's announcement. This prior is a free parameter that is influenced by the Fed's past track record in maintaining control over inflation. Agents compute a sequence of posterior probabilities $\{p_t\}^\infty_{t=t^*}$ by updating their prior in a (quasi) Bayesian way on the basis of observed realizations of the inflation rate and knowledge of the two (long-run) distributions of inflation centered at $\bar{\pi}^H$ and $\bar{\pi}^L$. The degree of Fed credibility is indexed by p_t.

15. Since $\bar{u}$ is independent of π_t, it can be interpreted as the "Natural Rate of Unemployment."

16. It is straightforward to append a money demand equation that determines how much money the Fed must supply in order to achieve the value of r_t given by (3). This would have no effect on the model's dynamics.

17. Evidence that the public perceived the statement in this way can be found in published newspaper reports of the time. See, for example, "Fed Takes Strong Steps to Restrain Inflation, Shifts Monetary Tactic," *The Wall Street Journal,* October 8, 1979, p. 1.

18. See, for example, Walsh (1988).

19. See Svensson (1997) and Ball (1997) for analyses of "efficient" monetary policy rules that minimize a discounted weighted-sum of the variances of inflation and output.

20. See Sargent (1998) for a model that seeks to endogenize the rise and fall of U.S. inflation.

We make the simplifying assumption that agents do not take into account the evolving nature of the inflation distribution during the transition to the new stationary equilibrium. Furthermore, we follow Meyer and Webster (1982), Baxter (1989), and Fuhrer and Hooker (1993), in assuming that the Fed's policy action is a once-and-for-all change. Thus, agents do not consider the possibility of any future regime shifts when forming their expectations.[21]

Under partial credibility, the public's beliefs regarding the reaction function parameters for $t \geq t^*$ evolve according to a version of Bayes' rule:

(10)
$$p_t = \frac{p_{t-1}\Pr(\pi_t \leq \pi_{t-1}|\bar{\pi}^L,\alpha^L_\pi,\alpha^L_y)}{p_{t-1}\Pr(\pi_t \leq \pi_{t-1}|\bar{\pi}^L,\alpha^L_\pi,\alpha^L_y) + (1-p_{t-1})\Pr(\pi_t \leq \pi_{t-1}|\bar{\pi}^H,\alpha^H_\pi,\alpha^H_y)},$$

with p_{t^*-1} given. The posterior probability $p_t \equiv \Pr(\bar{\pi}^L, \alpha^L_\pi, \alpha^L_y\,|\pi_t \leq \pi_{t-1})$ is computed by combining the prior probability $p_{t-1} \equiv \Pr\,(\bar{\pi}^L, \alpha^L_\pi, \alpha^L_y)$ with in-sample information. Specifically, the prior is weighted by $\Pr\,(\pi_t \leq \pi_{t-1}|\,\bar{\pi}^L, \alpha^L_\pi, \alpha^L_y)$, which represents the probability that inflation in period t will be lower than inflation observed in period $t-1$, conditional on the parameter combination $\{\bar{\pi}^L, \alpha^L_\pi, \alpha^L_y\}$. The relevant probability weights in (10) are given by

(11) $$\Pr(\pi_t \leq \pi_{t-1}|\bar{\pi}^L,\alpha^L_\pi,\alpha^L_y) = \int_{-\infty}^{\pi_{t-1}} \lambda(z)dz,$$

(12) $$\Pr(\pi_t \leq \pi_{t-1}|\bar{\pi}^H,\alpha^H_\pi,\alpha^H_y) = \int_{-\infty}^{\pi_{t-1}} h(z)dz,$$

where $\lambda(z)$ and $h(z)$ are the normal density functions that describe the stationary inflation distributions centered at $\bar{\pi}^L$ and $\bar{\pi}^H$, respectively.

Three features of the above specification warrant comment. First, the integrals in (11) and (12) are computed using the observation of π_{t-1}, *not* π_t. This is done to preserve the model's linearity in π_t. In particular, since p_t is used to construct the expectation $E_t\pi_{t+1}$ (as described below), the specification $p_t = p(\pi_t)$ would imply that (2) is nonlinear in the current period inflation rate. Maintaining linearity in π_t is desirable because it greatly simplifies the model solution procedure.[22]

Second, (11) and (12) imply that probability inferences are made using observations of a single economic variable (inflation), and that the relevant data sample includes only the most recent inflation rate, not the whole history of inflation rates $\{\pi_{t-i}\}_{i=1}^{t-t^*}$ observed since the announcement.[23] While our setup maintains tractability, it introduces some non-rationality into agents' forecasts to the extent that they ignore the potentially valuable information contained in the history of joint observations on inflation, interest rates, and the real output gap.[24]

Third, equation (10) differs from the standard classification formula for computing the conditional probability that a given observation comes from one of two populations with known densities.[25] In our model, the standard formula would take the form

(10′) $$p_t = \frac{p_{t-1}\lambda(\pi_{t-1})}{p_{t-1}\lambda(\pi_{t-1}) + (1-p_{t-1})h(\pi_{t-1})},$$

which says that p_t depends on the relative *heights* of the two density functions evaluated at π_{t-1}. In contrast, equation (10) says that p_t depends on the relative *areas* of the two density functions to the left of π_{t-1}. In quantitative simulations, we find that (10) quickens the pace of learning in comparison to (10′) and thus leads to more a realistic transition time between steady states. This occurs because (10) introduces an implicit bias into agents' inferences such that p_t is higher than that implied by (10′) for any given value of p_{t-1}. For the parameter values we consider, both specifications exhibit the desirable property that the credibility index p_t declines monotonically as inflation rises, for any given p_{t-1}.[26]

After computing the posterior probability, agents' expectations are formed as a weighted average of the rational forecasts that would prevail under each of the two possible reaction functions:

(13) $$\begin{aligned} E_t\pi_{t+1} = {} & p_t E_t\left[\pi_{t+1}|\bar{\pi}^L,\alpha^L_\pi,\alpha^L_y\right] \\ & +(1-p_t)E_t\left[\pi_{t+1}|\bar{\pi}^H,\alpha^H_\pi,\alpha^H_y\right], \end{aligned}$$

(14) $$\begin{aligned} E_t\rho_{t+1} = {} & p_t E_t\left[\rho_{t+1}|\bar{\pi}^L,\alpha^L_\pi,\alpha^L_y\right] \\ & +(1-p_t)E_t\left[\rho_{t+1}|\bar{\pi}^H,\alpha^H_\pi,\alpha^H_y\right], \end{aligned}$$

21. See Gagnon (1997) for a univariate model of inflation that relaxes both of the foregoing assumptions.

22. Our solution procedure is described in Section II.

23. The history of inflation *does* influence credibility, however, because it is incorporated into agents' prior beliefs, which are summarized by p_{t-1} in (10).

24. See Ruge-Murcia (1995) for a model where credibility is inferred using joint observations on fiscal and monetary variables.

25. See Anderson (1958), Chapter 6.

26. This property will obtain when the ratios
$$\left(\int_{-\infty}^{\pi} \lambda(z)dz\right)\Big/\left(\int_{-\infty}^{\pi} h(z)dz\right) \text{ and } (\lambda(\pi))/(h(\pi))$$
are monotonically decreasing in π.

$$E_t R_{t+1} = p_t E_t\left[R_{t+1}|\bar{\pi}^L, \alpha_\pi^L, \alpha_y^L\right] + (1-p_t)E_t\left[R_{t+1}|\bar{\pi}^H, \alpha_\pi^H, \alpha_y^H\right], \tag{15}$$

where p_t is given by (10). Since p_t is a function of past inflation, the model with rational expectations and partial credibility will now exhibit some of the backward looking characteristics of a model with adaptive expectations.[27]

II. ESTIMATION AND CALIBRATION

For the purpose of estimating parameters, we adopt a baseline model specification that incorporates full credibility. The resulting parameter set is then used for both credibility specifications in order to maintain comparability in the simulations. The data used in the estimation procedure are summarized in Table 1.

The model's reduced-form parameters are assumed to be "structural" in the sense that they are invariant to changes in the monetary policy reaction function (3). We attempt to gauge the reasonableness of this assumption by examining the sensitivity of the parameter estimates to different sample periods. Following Fuhrer (1996), we do not estimate the duration parameter but instead calibrate it to the value D = 28. This coincides with the sample average duration (in quarters) of a 10-year constant maturity Treasury bond. Equations (1) through (4) form a simultaneous system that we estimate using full-information maximum likelihood.[28] The estimation results are summarized in Table 2.

Despite small differences in our model specification and data, estimates from the full sample (1965:1 to 1996:4) are very much in line with those obtained by Fuhrer and Moore (1995b). With the exception of a_ρ and γ, the parameter estimates are all statistically significant. In contrast, the estimates from the first subsample (1965:1 to 1979:4) are highly imprecise, most likely due to the strong upward trends in U.S. inflation and nominal interest rates over this period. Estimates from the second subsample (1980:1 to 1996:4) are much closer to the full-sample results. Evidence of subsample instability seems to be concentrated mostly in the I-S curve parameters a_1, a_2, and a_ρ. Notice, however, that all subsample point estimates lie within one standard error of each other. We interpret these results to be reasonably supportive of the hypothesis that the reduced-form parameters a_1, a_2, a_ρ, $\bar{\rho}$ and γ do not vary across monetary policy regimes.

A comparison of the subsample point estimates of α_π and α_y suggests that the Fed has placed more emphasis on targeting inflation and less emphasis on stabilizing output in the period after 1980. For the simulations, we choose $\alpha_\pi^H = \alpha_y^H = 0.07$ for the high inflation regime and $\alpha_\pi^L = 0.10$ and $\alpha_y^L = 0.05$ for the low inflation regime. To complete the specification of the reaction function, we require values for $\bar{\pi}^H$ and $\bar{\pi}^L$. We choose $\bar{\pi}^H = 0.06$ to coincide with the sample mean from 1965:1 to 1979:4. Thus, we assume that the U.S. inflation rate prior to October 1979 can be characterized by a stationary distribution centered at 6 percent. While this assumption is undoubtedly false, it serves to illustrate the effects of partial credibility on the disinflation episode. Since $\bar{\pi}^L$ is intended to represent the new steady-state after the disinflation has been completed, we choose $\bar{\pi}^L = 0.03$ to coincide with the sample mean from 1985:1 to 1996:4. In computing this average, we omit the period of rapidly falling inflation from 1980:1 to 1984:4 because this can be interpreted as the transition to the new steady state.[29] For the other model parameters, we adopt the full-sample estimates in Table 2.

Our disinflation simulations abstract from stochastic shocks because these have the potential to obscure differences between the dynamic propagation mechanisms of

TABLE 1

QUARTERLY DATA, 1965:1 TO 1996:4

VARIABLE	DEFINITION
$\tilde{y}_t$	Deviation of log per capita real GDP from its linear trend.
π_t	Log-difference of GDP implicit price deflator.
r_t	Yield on 3-month Treasury bill.
R_t	Yield on 10-year constant-maturity Treasury bond.
u_t	Nonfarm civilian unemployment rate.

27. A similar effect obtains in the models of Fisher (1986), Ireland (1995), King (1996), Bomfim and Rudebusch (1997), and Bomfim, et al. (1997). In these models, credibility is determined by a backward-looking, linear updating rule. In contrast, Ball (1995) models credibility using a purely time-dependent probability measure.

28. We use the Matlab programs developed by Fuhrer and Moore (1995b), as modified to reflect the differences in our model specification and data.

29. The values $\bar{\pi}^H = 0.06$ and $\bar{\pi}^L = 0.03$ are very close to those used by Fuhrer (1996, figure IIb) to help reconcile the pure expectations theory of the term structure with U.S. nominal interest rate data.

TABLE 2

MAXIMUM LIKELIHOOD PARAMETER ESTIMATES

	1965:1 TO 1996:4		1965:1 TO 1979:4		1980:1 TO 1996:4	
PARAMETER	ESTIMATE	STANDARD ERROR	ESTIMATE	STANDARD ERROR	ESTIMATE	STANDARD ERROR
a_1	1.23	0.09	0.94	4.97	1.24	0.10
a_2	-0.26	0.08	0.10	4.62	-0.31	0.09
a_ρ	-0.20	0.12	-0.57	2.17	-0.05	0.05
$\bar{\rho}$	0.02	0.01	0.02	0.36	0.00	0.04
γ	0.01	0.01	0.04	0.47	0.01	0.01
α_π	0.06	0.03	0.07	1.04	0.10	0.05
α_y	0.08	0.03	0.07	1.05	0.05	0.06
$\bar{\pi}$	0.05	0.01	0.04	0.45	0.05	0.01

the two credibility specifications.[30] We assume, however, that agents make decisions *as if* stochastic shocks were present. This assumption is necessary for a meaningful analysis of credibility because without stochastic shocks, agents can always learn the true values of $\bar{\pi}$, α_π, and α_y within four periods. To compute the integrals in (11) and (12), we simply calibrate the standard deviations of the two long-run inflation distributions centered at $\bar{\pi}^H$ and $\bar{\pi}^L$. For the high inflation regime, we choose $\sigma_{\pi H} = 0.023$ to coincide with the sample standard deviation from 1965:1 to 1979:4. For the low inflation regime, we choose $\sigma_{\pi L} = 0.011$ to coincide with the sample standard deviation from 1985:1 to 1996:4. In computing this statistic, we once again exclude the transition period from 1980:1 to 1984:4.

For the steady-state unemployment rate, we choose $\bar{u} = 0.06$ to coincide with the average over the full sample. Given $\bar{u}$, we estimate the parameters of Okun's law (8) using ordinary least squares to obtain $b_1 = 0.96$, $b_2 = -0.30$, $b_3 = 0.10$, and $b_4 = 0.18$, which are all statistically significant.

Our solution procedure can be briefly summarized as follows. Given a set of parameters, we solve the full-information version of the model for each of the two reaction functions described by $\{\bar{\pi}^H, \alpha_\pi^H, \alpha_y^H\}$ and $\{\bar{\pi}^L, \alpha_\pi^L, \alpha_y^L\}$. In each case, the solution consists of a set of time-invariant linear decision rules for π_t, ρ_t, and R_t, defined in terms of the "state" vector $s_t = \{\tilde{y}_{t-1}, \tilde{y}_{t-2}, \pi_{t-1}, \rho_{t-1}, r_{t-1}\}$. The decision rules for $\tilde{y}_t$ and r_t are simply given by (1) and (3), respectively. For each reaction function, we use the decision rules to construct linear expressions for the conditional expectations $E_t\,[\pi_{t+1}|\,\bar{\pi}^i, \alpha_\pi^i, \alpha_y^i]$, $E_t\,[\rho_{t+1}|\,\bar{\pi}^i, \alpha_\pi^i, \alpha_y^i]$, and $E_t\,[R_{t+1}|\bar{\pi}^i, \alpha_\pi^i, \alpha_y^i]$, $i = L, H$. Next, we form the unconditional expectations $E_t\,\pi_{t+1}$, $E_t\rho_{t+1}$, and E_tR_{t+1} using the current value of p_t (which does not depend on π_t) and (13) through (15). Finally, the unconditional expectations are substituted into (2), (4), and (6) which, together with (1) and (3), form a system of five linear equations in the five unknowns $\tilde{y}_t$, π_t, ρ_t, r_t, and R_t.

Under full credibility, it is straightforward to show that the model possesses a unique, stable equilibrium for the parameter values we employ.[31] Under partial credibility, agents use observations of an endogenous variable (inflation) to form expectations that are crucial for determining the period-by-period values of that same variable. The presence of this dynamic feedback effect between the trajectory of inflation and the inputs to the learning process may create an environment where learning goes astray. In particular, there is no way to guarantee that the model will converge to a new steady state with $\bar{\pi} = \bar{\pi}^L$.[32] However, for the parameter values we employ, we find that convergence is achieved in the quantitative simulations.[33]

30. For studies that explore disinflation dynamics in models subject to stochastic shocks, see Meyer and Webster (1982), Orphanides, et al. (1997), and Bomfim and Rudebusch (1997).

31. The steady states associated with the two reaction functions both exhibit the well-known saddle point property.

32. In contrast, Taylor (1975), Meyer and Webster (1982), Baxter (1989), and Andolfatto and Gomme (1997), among others, consider Bayesian learning models in which agents' expectations do not affect the evolution of the variables they form expectations about. Hence, convergence follows from standard results on the asymptotic properties of estimators.

33. Marcet and Sargent (1989) develop an analytical framework for proving the convergence of "self-referential" models in which the evolution of an endogenous variable is governed by an adaptive learning process.

III. QUANTITATIVE RESULTS

Deterministic Disinflation Simulations

In our experiments with the model, we find that a very low prior p_{t^*-1} is needed for the model to generate an endogenous inflation scare. Therefore, in our specification with partial credibility, we set the initial prior to 0.001 percent. This choice also reflects our view (noted earlier) that the Federal Reserve had very little credibility at the start of the Volcker disinflation.[34]

The evolution of credibility is shown in Figure 1A. With full credibility, p_t jumps immediately to 100 percent on the strength of the Fed's announcement at $t^* = 0$. With partial credibility, p_t increases slowly over time as agents observe that π_t is falling (see Figure 1B). This feature of the model is consistent with the findings of Hardouvelis and Barnhart (1989) who show that an empirical proxy for Fed credibility increased only gradually in the period following October 1979. Moreover, they find that credibility is statistically linked to the rate of inflation.[35]

Credibility approaches the value p_t = 100 percent approximately 16 quarters after the change in Fed policy. Once full credibility is reached, Bayes' rule (10) implies that p_t = 100 percent will be sustained forever. However, as long as p_t < 100 percent by even a single decimal point, the economy will be susceptible to an inflation scare. In the simulation, credibility peaks at a value of 99.97742 percent and then begins to deteriorate rapidly. This loss of credibility is triggered by the period of rising inflation (observed in Figure 1B) that results from the dynamic overshooting characteristics of the model.[36]

Figure 1B shows that disinflation proceeds more slowly under partial credibility. The intuition for this result follows directly from equation (2). With partial credibility, the sluggish behavior of $E_t\pi_{t+1}$ delays the response of current inflation π_t to the policy change. This, in turn, delays the accumulation of credibility, which feeds back to inflation expectations.[37]

Figure 2A shows that both credibility specifications imply an initial monetary contraction, as evidenced by an increase in the short-term nominal interest rate r_t.[38] With partial credibility, the Fed undertakes a greater degree of monetary tightening, as measured by the peak level of r_t. This is due to the form of the reaction function (3) that makes r_t an increasing function of the distance $\pi_t - \overline{\pi}^L$. Since π_t falls more slowly under partial credibility, the level of r_t implied by (3) is higher. Moreover, the sluggish adjustment of $E_t\pi_{t+1}$ means that a higher level of inflation is built into expectations of *future* short rates. These two effects combine to raise the level of the current long rate R_t in comparison to the model with full credibility. Figure 2B shows that, under partial credibility, the inertia built into agents' inflation forecasts is sufficient to cause R_t to increase slightly in response to the tighter monetary policy. In contrast, full credibility generates an immediate *fall* in R_t as agents quickly lower their inflation expectations. Empirical studies generally indicate that tighter monetary policy leads to an increase in long-term nominal interest rates.[39]

The key feature of Figure 2B is the inflation scare that occurs about 24 quarters after the change in Fed policy. The scare produces a 2 percentage point jump in the long-term rate R_t that coincides with the interval of deteriorating credibility and rising inflation described above. Notice that the jump in R_t takes place in the absence of any aggressive tightening by the Fed. In fact, Figure 2A shows that the short-term rate r_t is actually *falling* during the inflation scare. Equation (13) implies that a decrease in p_t will cause expectations of future inflation to be revised upward. This forecast of higher inflation implies higher future values of r_t which, in turn, are incorporated into R_t via the term structure equation (7). In this way, the model generates an endogenous inflation scare.

Figures 3 and 4 show that the Fed's tighter monetary policy leads to a prolonged recession: real output declines relative to trend, and the unemployment rate goes up. Notice that the recession is considerably more severe in the case of partial credibility. This result helps to provide some insight into the high unemployment rates observed during the Volcker disinflation which, as we argued earlier, was initiated when the Fed's credibility was very low.

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34. A similar view is put forth by Mankiw (1994), who shows that forecasts made by the Council of Economic Advisers in January 1981 predicted a gradual and moderate decline in the inflation rate, in contrast to the rapid and pronounced disinflation that actually occurred under Fed Chairman Volcker.

35. The Hardouvelis-Barnhart measure of credibility is inversely proportional to the response of commodity prices (such as gold and silver) to unanticipated changes in the M1 money stock.

36. For the parameter values we employ, the model's dynamical system exhibits complex eigenvalues which give rise to damped oscillatory behavior.

37. In the words of Fed Chairman Volcker: "Inflation feeds in part on itself, so part of the job of returning to a more stable and more productive economy must be to break the grip of inflationary expectations." See Volcker (1979), pp. 888–889.

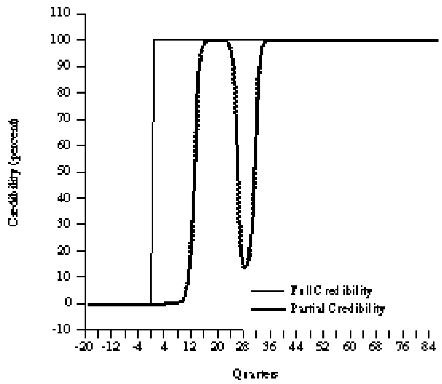
38. Since r_t rises and $\tilde{y}_t$ falls, a traditional Keynesian money demand equation with a predetermined price level would imply a contraction of the nominal money stock.

39. See Akhtar (1995) for a survey of the enormous empirical literature on this subject.

FIGURE 1

Credibility and Inflation

A. Model Credibility
Prior = 0.001%



B. Model Inflation Rate
Prior = 0.001%

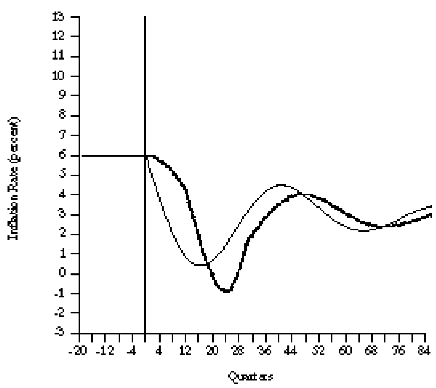
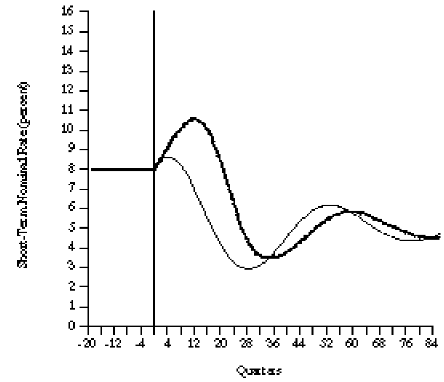


FIGURE 2

Nominal Interest Rates

A. Model Short-Term Nominal Interest Rate
Prior = 0.001%



B. Model Long-Term Nominal Interest Rate
Prior = 0.001%

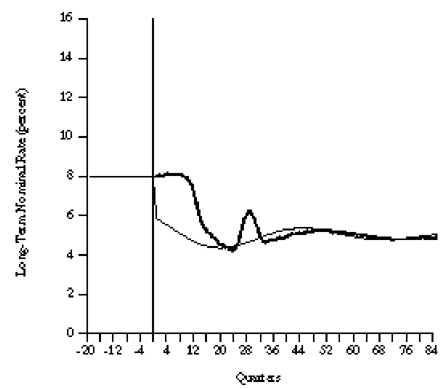


FIGURE 3

Model Real Output Gap

Prior = 0.001%

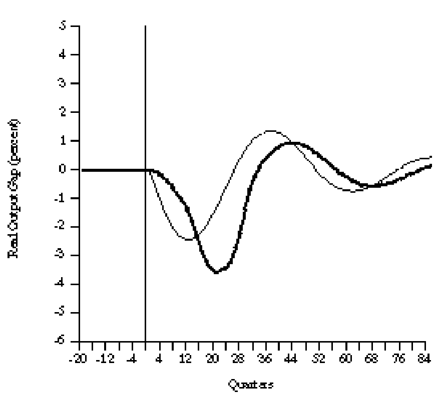


FIGURE 4

Model Unemployment Rate

Prior = 0.001%

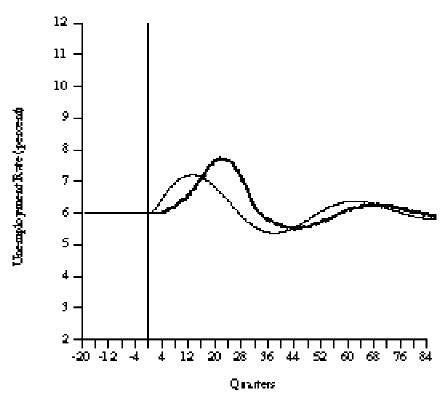
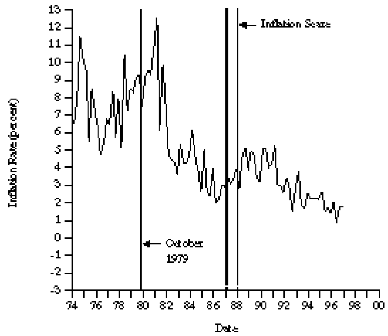


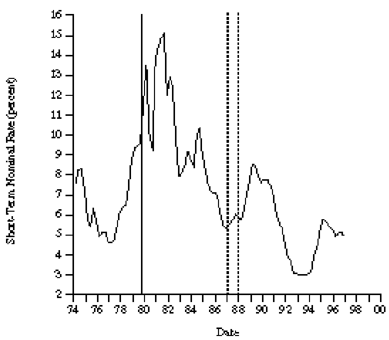
FIGURE 5

U.S. DATA

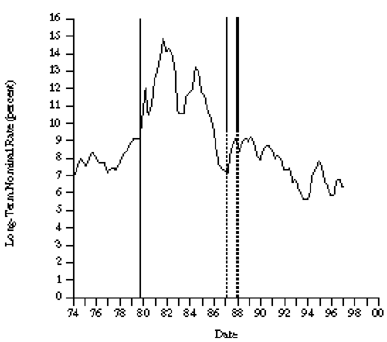
A. U.S. INFLATION RATE



B. U.S. SHORT-TERM NOMINAL INTEREST RATE



C. U.S. LONG-TERM NOMINAL INTEREST RATE



D. U.S. REAL OUTPUT GAP

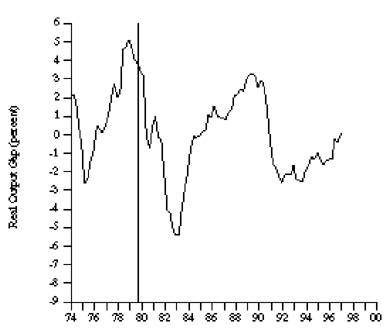
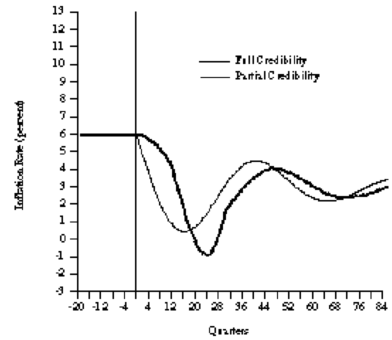


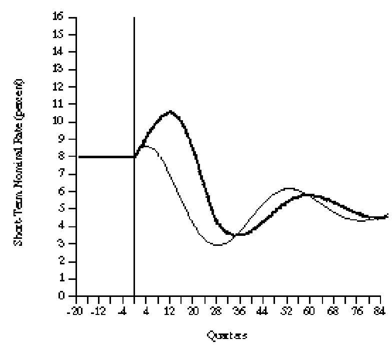
FIGURE 6

MODEL SIMULATIONS

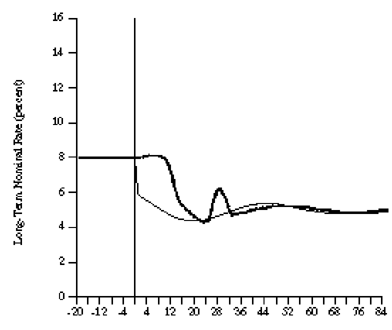
A. MODEL INFLATION RATE: PRIOR = 0.001%



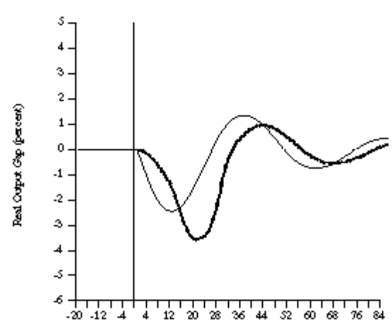
B. MODEL SHORT-TERM NOMINAL INTEREST RATE: PRIOR = 0.001%



C. MODEL LONG-TERM NOMINAL INTEREST RATE: PRIOR = 0.001%



D. MODEL REAL OUTPUT GAP: PRIOR = 0.001%



The time paths of the model variables in Figures 3 and 4 illustrate a potentially important stabilization property of full credibility. In particular, stabilization of the model is aided by the elimination of the backward-looking dynamics associated with the learning process. This result is consistent with the findings of Fuhrer (1997), who shows that a stronger *forward-looking* component in the contracting equation (2) helps to stabilize the model.[40]

Comparison with Volcker Disinflation

Figures 5 and 6 compare the evolution of U.S. macroeconomic variables during the Volcker disinflation with the corresponding variables in our model. The vertical line in the U.S. figures marks the start of the Volcker disinflation in October 1979. The model captures many of the qualitative features of the Volcker disinflation. Notice that the U.S. variables appear to exhibit some low frequency, damped oscillations that resemble the dynamic overshooting characteristics of the model variables. It should be noted, however, that the 16-year period following October 1979 may include some additional monetary policy actions that are not present in the model. For example, Taylor (1993) shows that the time path of the federal funds rate since 1987 is well-described by a policy rule with an inflation target of 2 percent (see footnote 12). In addition, Romer and Romer (1994) find evidence that the Federal Reserve made a deliberate decision to reduce inflation in December 1988.

In Figures 5A–C, we highlight the classic pattern of an inflation scare that can be observed in U.S. data about 29 quarters after the start of the Volcker disinflation. Specifically, from 1986:4 to 1987:4, the yield on a 10-year Treasury bond increased sharply from 7.3 percent to 9.1 percent (Figure 5C), despite only a small increase in the 3-month Treasury bill rate from 5.3 to 6.0 percent (Figure 5B). Over this same period, the inflation rate increased from 2.9 to 3.9 percent (Figure 5A). This pattern fits our definition of an inflation scare, suggesting that the increase in the U.S. long rate was driven by an upward shift in the public's expectations of future inflation. Notice that the 1987 scare episode occurred shortly after U.S. inflation "bottomed out" and again started to rise. Interestingly, this feature of the data resembles the dynamic overshooting behavior of inflation in the model (Figure 6A). Given our intepretation of the data, the 1987 scare episode illustrates the long memory of the public in recalling the high and variable inflation of the 1970s, and serves as an important reminder of the fragility of Federal Reserve credibility.[41]

As noted earlier in the introduction, Goodfriend (1993) identifies three other inflation scare episodes in U.S. data that occur much closer to the start of the Volcker disinflation. Our model does not capture these episodes because the dynamic overshooting behavior of the inflation rate (which triggers the inflation scare) takes a long time to evolve. We note, however, that our simulations abstract from stochastic shocks which may have played a role in triggering these earlier episodes.

Another feature of the U.S. data that we do not capture is the dramatic increase in the long-term nominal interest rate in the period following October 1979 (Figure 5C). In Huh and Lansing (1998), we show that a version of this model that combines adaptive expectations with partial credibility can exhibit more sluggish adjustment in inflation expectations. As a result, we find that R_t can rise significantly in response to a tightening of monetary policy.

IV. Conclusion

This paper developed a simple, quantitative model of the U.S. economy to show how an inflation scare may occur when the Federal Reserve lacks full credibility. Our simulation exercise was reasonably successful in capturing the magnitude and timing of the 1987 U.S. inflation scare episode that produced a sharp increase in the 10-year Treasury bond yield. Our model also captures many of the qualitative features of the Volcker disinflation of the early 1980s.

The potential for an inflation scare will continue to exist so long as the public believes that the U.S. economy may someday return to an environment of high and variable inflation. One way of addressing this problem is through legislation designed to enhance credibility by requiring the Fed to pursue some notion of "price stability" as its primary or sole objective. An arrangement such as this was put in place for the central bank of New Zealand in 1989.[42]

40. For a related discussion, see Taylor (1980, section IV).

41. See Gagnon (1996) for some cross-country evidence that inflation expectations exhibit a "long memory" of past inflation.

42. See Romer and Romer (1997) for a discussion regarding the merits of legislated rules and other institutional arrangements for the conduct of monetary policy.

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