WHY INFLATION ROSE AND FELL: POLICY-MAKERS' BELIEFS AND U. S. POSTWAR STABILIZATION POLICY*

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This paper provides an explanation for the run-up of U. S. inflation in the 1960s and 1970s and the sharp disinflation in the early 1980s, which standard macroeconomic models have difficulties in addressing. I present a model in which rational policy-makers learn about the behavior of the economy in real time and set stabilization policy optimally, conditional on their current beliefs. The steady state associated with the self-confirming equilibrium of the model is characterized by low inflation. However, prolonged episodes of high inflation ending with rapid disinflations can occur when policy-makers underestimate *both* the natural rate of unemployment *and* the persistence of inflation in the Phillips curve. I estimate the model using likelihood methods. The estimation results show that the model accounts remarkably well for the evolution of policy-makers' beliefs, stabilization policy, and the postwar behavior of inflation and unemployment in the United States.

I. Introduction

This paper aims to explain the behavior of inflation and unemployment in the United States. Figure I presents a plot of the annualized quarterly growth rate of the GDP deflator and the total civilian unemployment rate over the postwar period. The striking feature of the graph is the long and pronounced run-up of inflation, which occurred in the 1960s and 1970s. This episode, known as the Great Inflation, is not just "America's only peacetime inflation" [DeLong 1997], but has also been called "the greatest failure of American macroeconomic policy in the postwar period" [Mayer 1999].

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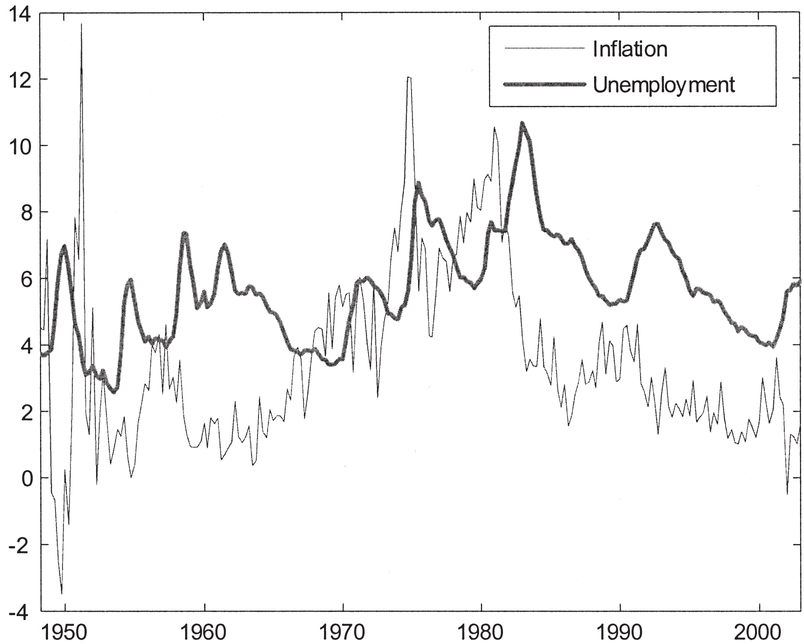

FIGURE I
U. S. Inflation and Unemployment

At least four stylized facts characterize the Great Inflation.

- *Dimension.* Between 1963 and 1981 the inflation rate in the United States rose by more than 9 percentage points. If we exclude the peak in 1974 (which is due to the effect of the first oil price shock), the rate of increase was approximately constant.
- *Duration.* The episode of high inflation lasted for more than twenty years. Inflation started to increase around 1963 and came back under control, at a level of about 2 percent, only around 1985.
- *Asymmetry.* The episode of high inflation was asymmetric. In the early 1980s the duration of the so-called "Volcker disinflation" was much shorter than the phase of rising inflation.
- *Unemployment lagged inflation.* Unemployment lagging behind inflation is a general characteristic of the business cycle. However, this feature of the data was particularly

evident in the period of high inflation, with unemployment peaking always a few quarters after inflation.

This paper puts forward a theory of the behavior of inflation and unemployment, which fits the U. S. data well and, in particular, explains all four of the stylized facts above. This theory is based on the evolution of policy-makers' beliefs about the structure of the economy.

Previous attempts to explain the Great Inflation fall apart in three categories, which I label the "bad luck," the "lack of commitment," and the "policy mistakes" views. I briefly discuss each of these branches of literature below.

The "back luck" view. The first type of explanations is based on bad luck, in view of the fact that it has been well documented that the volatility of the exogenous, nonpolicy shocks was higher in the 1960s and 1970s than in the last two decades of the century (see, for instance, Cogley and Sargent [2003], Kim and Nelson [1999], McConnell and Perez-Quiros [2000], Sims and Zha [2004], and Stock and Watson [2002]). However, although nonpolicy shocks definitely played an important role, Primiceri [2005b] presents a model that accounts for stochastic volatility and shows that it is hard to reconcile the existing estimates with the exceptional dimension and duration of the Great Inflation.

The "lack of commitment" view. The second class of explanations is what Christiano and Fitzgerald [2003] have called the "institution vision of inflation." According to this view, inflation was high in the 1960s and 1970s because policy-makers did not have any incentive to keep inflation low. The motivation for this relies on the time-consistency problem of optimal policy, first emphasized by Kydland and Prescott [1977] and Barro and Gordon [1983]. The importance of this line of research has recently been emphasized by Chari, Christiano, and Eichenbaum [1998], Christiano and Gust [2000], and Christiano and Fitzgerald [2003].

However, the inflation bias generated by the time-consistency problem seems to be quantitatively too small to explain the high inflation of the 1960s and 1970s (for example, see Reis [2003]). Ireland [1999] formally tests the inflation bias hypothesis on U. S. data. While he is not able to reject it, his estimates suggest the presence of an inflationary bias of small magnitude. Moreover, it is hard to reconcile the time-consistency view with the rapid Volcker disinflation. In fact, it is not clear what exactly changed between the pre- and post-1980s period from the institutional point of view.[1] The final difficulty with the "lack of commitment" approach is the fact that it would predict the unemployment gap leading, rather than lagging inflation. This is due to the fact that the advantages of inflationary surprises depend on the level of unemployment. As mentioned above, this is clearly at odds with the data.

The "policy mistakes" view. This approach focuses on policy mistakes and stresses that in the 1960s and 1970s monetary policy-makers were not as good as the ones of the last two decades. For example, many authors have argued that U. S. monetary policy was less responsive to inflationary pressures under the Fed chairmanship of Arthur Burns than under Paul Volcker and Alan Greenspan (among others, see Boivin and Giannoni [2002], Clarida, Gali, and Gertler [2000], Cogley and Sargent [2001], Judd and Rudebusch [1998], and Lubik and Schorfheide [2004]).[2]

In this respect, the line of research started by Orphanides represents an attempt to rationalize why the policy authorities behaved so differently in the pre- and post-1980s period. Orphanides [2000, 2002] has argued that policy-makers in the 1970s overlooked a break in potential output. They overestimated potential output leading to overexpansionary policies, which ultimately resulted in high inflation. Among others, this explanation has also been proposed by Cukierman and Lippi [2002], Lansing [2002], Bullard and Eusepi [2003], Reis [2003], and Tambalotti [2003]. While this strand of literature represents a step forward, the dimension of the high inflation episodes explained by such models is usually much lower than what we observe in the data, unless the model is augmented with additional propagation mechanisms like, for instance, private sector learning (as in Orphanides and Williams [2003]). Furthermore, the explanations based on the misperception of potential output fail to address the

1. Recent work has made some progress in this direction. Sargent [1999], for example, explains the disinflation as escape dynamics from the inflation-biased equilibrium. Rogoff [2003] argues that Central Banks' lower incentive to inflate is related to globalization and the consequent increase in world competition. Albanesi, Chari, and Christiano [2003], instead, analyze the lack of commitment problem in an optimizing-agents model and show the existence of multiple equilibria, which can potentially explain the disinflation.

2. This view is controversial. Other studies have in fact found either little evidence of changes in the systematic part of monetary policy (for example, Bernanke and Mihov [1998], Hanson [2003], Leeper and Zha [2002], and Primiceri [2005a]) or no evidence of unidirectional drifts in policy toward a more active behavior [Sims 2001; Sims and Zha 2004].

Volcker disinflation, unless an exogenous shift in policy-makers' preferences is specified (for example, as in Bullard and Eusepi [2003]).

While there is clearly some truth in all of these theories, they also seem to have difficulties in addressing at least some of the stylized facts of the hump-shaped behavior of inflation and unemployment. This paper proposes instead an explanation of the Great Inflation that matches all these stylized facts.

I present a model, in which rational policy-makers form their beliefs about the behavior of the economy in real time and set stabilization policy optimally, conditional on the information available to them. Although the equilibrium of the model is characterized by low inflation, episodes of high inflation and unemployment can occur when policy-makers simultaneously underestimate *both* the natural rate of unemployment *and* the persistence of inflation in the Phillips curve. Such initial conditions result in peculiar dynamics of policy-makers' beliefs, ultimately also affecting their perception of the slope of the Phillips curve and of the cost of the inflation-unemployment trade-off.

Intuitively, if real-time policy-makers underestimate the natural rate of unemployment, this results in overexpansionary policies and higher inflation. Moreover, if policy-makers' estimate of the persistence of inflation in the Phillips curve is also downward biased, they rationally choose not to react strongly to inflation, amplifying the initial effect. The reason is that the more stationary inflation is perceived to be, the sooner it is expected to revert to its mean and the less urgent is the need for anti-inflationary action. This period of "overoptimism" ends when inflation reaches a level that concerns policy-makers. However, when policy-makers start reacting to inflation, pushing unemployment above the *perceived* natural rate does not seem to reduce inflation. This is because they still have a downward biased estimate of the natural rate of unemployment. In this period of "overpessimism," they temporarily and mistakenly perceive a very costly inflation-unemployment trade-off, which explains why anti-inflationary policy is postponed even further. The disinflation occurs only when the perceived inflation-unemployment trade-off becomes favorable, relative to the level of inflation.

Among others, Orphanides [2000], DeLong [1997], and Romer and Romer [2002] have argued in favor of the policy misperception of potential output and the natural rate of unemployment in the 1960s and 1970s. Policy-makers' misperception of the persistence of inflation in the Phillips curve in the 1960s is also no longer controversial. For example, Blanchard and Fischer [1989] and Mayer [1999] have noted that, at least until the early 1970s, most of the econometric studies underestimated the persistence of inflation. In relation to the overpessimism phase, DeLong [1997], Romer and Romer [2002], and Cogley and Sargent [2004] have emphasized that policy was cautious in the 1970s because the cost of lowering inflation seemed too high.

From a quantitative and statistical standpoint, I show that the evolution of policy-makers' beliefs about the coefficients of the Phillips curve is very important in explaining the behavior of inflation and unemployment. I estimate the model using likelihood methods. The estimated version of the model accounts remarkably well for the evolution of policy-makers' beliefs, stabilization policy, and the postwar behavior of inflation and unemployment in the United States.

The importance of policy-makers' learning dynamics has been recognized by many authors. In the context of the "natural rate" literature, policy-makers' learning has been introduced by Sims [1988]. Theoretical advances include Sargent [1999], Cho, Williams, and Sargent [2002], and Williams [2003]. Empirical studies include Chung [1990], Sargent [1999], Cogley and Sargent [2004], and Sargent, Williams, and Zha [2004]. The main insight of this literature is that policy-makers' learning introduces temporary deviations from the model's equilibrium, which is characterized by an inflation bias. These temporary deviations are in the direction of the optimal, low inflation outcome. Unlike these studies, in this paper the equilibrium outcome is a low inflation regime. Nevertheless, the model explains the run-up of U. S. inflation in the 1960s and 1970s and the sharp disinflation in the early 1980s. Although the explanation roughly belongs to the "policy mistakes" category, in this paper policy-makers are assumed to be rational and optimizing. As a consequence, I find that the mismeasurement of the natural rate of unemployment alone is not sufficient to generate fluctuations of the inflation rate comparable to what we observe in the data. This differs importantly from Orphanides [2000] and other similar approaches.

The paper is organized as follows. Section II presents the theoretical model of the economy and policy-makers' behavior. Section III offers a model-based interpretation of the Great Inflation. Section IV focuses instead on statistical evidence, i.e., estimation, fit, and quantitative simulation results. Section V makes an attempt to uncover the deeper reasons for the Great Inflation, i.e., why policy-makers underestimated the persistence of inflation in the Phillips curve in the 1960s. Section VI concludes with some final remarks.

II. Imperfect Information and Inflation-Unemployment Dynamics

In this section I present a simple model of inflation-unemployment dynamics when policy-makers have imperfect information. The source of imperfect information is the fact that policy-makers do not know the exact model of the economy. In particular, they are uncertain about the value of the model's parameters. Therefore, policy-makers update their beliefs about the model's unknowns in every period and implement optimal policy, conditional on their current beliefs. In turn, the policy variable affects the behavior of inflation and unemployment because it enters the model describing the true evolution of key macroeconomic variables.

II.A. The Model Economy

As a "true" model of the economy, I consider a simple rational expectations model that can be rewritten as a backward-looking one. Even if conceptually similar to modern New-Keynesian specifications, the benchmark model is more in the spirit of the empirical literature following along the lines of King, Stock, and Watson [1995] and, more recently, Gordon [1997, 1998], Rudebusch and Svensson [1999], and Staiger, Stock, and Watson [2001].

This framework is not only tractable and convenient for estimation, but also is simple and transparent, providing a clear intuition for the role played by policy-makers' learning dynamics in the behavior of inflation and unemployment. Primiceri [2005b] shows that integrating learning dynamics in a forward-looking specification is instead computationally more expensive, and does not substantially alter the results presented below.

The private sector part of the model is described by the following equations:

$$\pi_t = \pi_t^e - \tilde{\theta}(L)(u_{t-1} - u_{t-1}^N) + \varepsilon_t; \tag{1}$$

$$(u_t - u_t^N) = \rho(L)(u_{t-1} - u_{t-1}^N) + V_{t-1} + \eta_t; \tag{2}$$

$$u_t^N = (1 - \gamma)u^* + \gamma u_{t-1}^N + \tau_t. \tag{3}$$

Equation (1) represents a standard expectation-augmented Phillips curve, where π_t is the inflation rate, π_t^e is the agents' expected inflation rate, u_t is the unemployment rate, and u_t^N is the time-varying natural rate of unemployment. $\tilde{\theta}(L)$ is a lag polynomial, and ε_t is a random innovation, assumed to be *i.i.d.* $N(0,\sigma_\varepsilon^2)$.[3] I assume that some agents are fully rational, while the rest of them form their expectations adaptively, so that

$$\pi_t^e = (1 - \tilde{\alpha}(1))E_{t-1}\pi_t + \tilde{\alpha}(L)\pi_{t-1}, \tag{4}$$

where $\tilde{\alpha}(L)$ is a lag polynomial. Substituting (4) into (1), it is possible to solve explicitly for $E_{t-1}\pi_t$, which leads to the following familiar Phillips curve:

$$\pi_t = \alpha(L)\pi_{t-1} - \theta(L)(u_{t-1} - u_{t-1}^N) + \varepsilon_t, \tag{5}$$

where $\alpha(L) = \tilde{\alpha}(L)/\tilde{\alpha}(1)$ and $\theta(L) = \tilde{\theta}(L)/\tilde{\alpha}(1)$. Note that, no matter what the exact fraction of agents with rational expectations is, $\alpha(1) = 1$, implying the absence of a long-run trade-off between unemployment and inflation, which is consistent with the natural rate hypothesis. The interpretation of (5) is straightforward: the inflation rate changes either because of a random "cost push" term or because unemployment is not in line with the natural rate. There are clearly alternative representations of an aggregate supply equation, but it is important to stress that the absence of a long-run trade-off (or, at least, a very steep curve in the long run) is the only characteristic of the Phillips curve which is important for the results presented in this paper.

Equation (2) is a very simple aggregate demand equation, where $\rho(L)$ is a lag polynomial, η_t is an *i.i.d.* $N(0,\sigma_\eta^2)$ random innovation, and V_t is a variable controlled by policy-makers. In other words, unemployment deviates from the natural rate either because of a random shock or because of policy-makers' decisions about stabilization policy.

A natural interpretation of the policy variable V_t is of the real rate of interest, at least in the class of models in which expected inflation is predetermined. More generally, V_t can be thought of as capturing the joint effect of monetary and fiscal policy. In particular, this modeling strategy avoids complications related to the specification of two aspects of the policy process: the relative importance of the monetary and fiscal policy actions on real

3. The case of heteroskedastic innovations is particularly interesting in the context of learning models and is analyzed in Primiceri [2005b].

activity and the particular channels through which monetary and fiscal policy affect real activity. This is in the spirit of the recent renovated interest on the effect of fiscal policy (see, among others, Blanchard and Perotti [2002] and Mountford and Uhlig [2002]) and the direct role of monetary aggregates in macro models [Favara and Giordani 2002; Leeper and Roush 2003].

Equation (3) describes the exogenous stochastic process for the natural rate of unemployment, which is assumed to evolve as an AR(1), where τ_t is *i.i.d.* $N(0,\sigma_\tau^2)$. u^* represents the unconditional expectation of u_t^N. This assumption on the evolution of u_t^N is standard in the literature (see, for instance, Staiger, Stock, and Watson [2001], although they set $\gamma = 1$ in their empirical specification).

Finally, notice that the joint process for inflation and unemployment will be stationary, unless policy is completely passive. In fact, movements of the policy variable V in response to inflation fluctuations will generate mean reversion in the inflation-unemployment joint stochastic process, despite the fact that the sum of coefficients on past inflation in the Phillips curve is restricted to one.

II.B. Optical Policy under Imperfect Information

The value of the policy variable V is chosen in every period by policy-makers. They base their decision on the available information and on current beliefs about the state of the economy. I assume that policy-makers know the structure of the true Phillips curve and aggregate demand of the economy (equations (5) and (2)), but they do not know the value of the coefficients of these equations. Moreover, policy-makers are uncertain about both, the current level and the stochastic process for the natural rate (equation (3)). As illustrated in the previous subsection, in the true model of the economy the coefficients are constant, while the natural rate evolves stochastically over time.

Policy-makers are assumed to behave as "anticipated utility" decision makers, as recommended by Kreps [1998]. In other words, policy-makers estimate the natural rate and the other coefficients of the model in every period and treat these estimates as true values, neglecting both estimates' uncertainty and the possibility of future updates. This modeling approach is common to most of the macroeconomic literature on learning (see, for instance, Sargent [1993, 1999] or Evans and Honkapohja [2001]) and has been shown to provide a very accurate approximation of the solution of the Bayesian decision problem [Cogley and Sargent 2005]. In particular, notice that neglecting the possibility of future updates rules out voluntary experimentation, which could be used to improve future estimates. This seems a realistic assumption for the behavior of a central bank (see Blinder [1998] and Lucas [1981]).[4] Moreover, Cogley, Colacito, and Sargent [2005] have shown that the potential gains from experimentation are small, in the context of a simplified version of this model.

Policy-makers' beliefs about unobservables and the model's constant coefficients are denoted by circumflexes. All these beliefs are formed at time t. In particular, $\hat{u}^N_{s|t}$ indicates the estimate at time t of the value of the natural rate at time s. Policy-makers compute the optimal plan for the policy variable $\{V_{s|t}\}_{s=t}^{\infty}$, by solving the following optimal control problem:

$$\text{(6)}\quad \min_{\{V_{s|t}\}_{s=t}^{\infty}} L_t = \hat{E}_t \sum_{s=t}^{\infty} \delta^{s-t}[(\pi_s - \pi^*)^2 + \lambda(u_s - k\hat{u}^N_{s|t})^2 + \phi(V_s - V_{s-1})^2],$$

$$\text{(7)}\quad \text{subject to } \pi_s = \hat{c}_{\pi,t} + \hat{\alpha}_t(L)\pi_{s-1} - \hat{\theta}_t(L)(u_{s-1} - \hat{u}^N_{s-1|t}) + \hat{\varepsilon}_s, \quad s \geq t+1,$$

$$\text{(8)}\quad (u_s - \hat{u}^N_{s|t}) = \hat{c}_{u,t} + \hat{\rho}_t(L)(u_{s-1} - \hat{u}^N_{s-1|t}) + V_{s-1|t} + \hat{\eta}_s, \quad s \geq t+1.$$

L represents the familiar quadratic loss function, which depends on deviations of inflation and unemployment from the respective targets. The circumflex on the expectation operator indicates that the expectation is taken with respect to the probability distribution generated by the perceived model. λ represents the weight on the unemployment objective. Notice that, as in Barro and Gordon [1983], the target for the unemployment rate is given by $k\hat{u}^N_{s|t}$. When $k = 0$, the unemployment target is equal to zero, and policy-makers' preferences resemble Kydland and Prescott's [1977]. This would be the case in which the policy time-consistency problem is most pronounced. On the other hand, when $k = 1$, the target is the natural rate, and the time-consistency and the related inflation bias completely disappear from the policy problem. Blinder [1998], among others, has argued in favor of these kinds of policy preferences. The loss function has also a "smooth-

4. For an example of alternative approaches, see Beck and Wieland [2002] and Wieland [2000a, 2000b].

ing" component, which penalizes big shifts of the policy variable. From an empirical perspective, this term is crucial in order to match the actual policy behavior because it helps to account for the strong autocorrelation shown by the instruments of economic policy [Dennis 2001; Favero and Rovelli 2003; Soderstrom, Soderlind, and Vredin 2002]. See also Woodford [2003] for an overview of the theoretical desirability of the smoothing term in the monetary policy context. Moreover, it is easy to think of models in which instrument smoothing is also desirable for fiscal policy (for example, Barro [1979]).

The coefficients δ, π^*, λ, k, and ϕ represent the preferences of policy-makers and, therefore, are known to them. Policy-makers minimize their loss function subject to two constraints, (7) and (8), and their current estimate of the natural rate. These constraints are the estimated counterparts of the true Phillips curve and aggregate demand equations. Observe that in the policy-makers' model $\hat{\alpha}(1)$ is not constrained to be equal to 1 and $\hat{c}_\pi$ in (7) controls their beliefs about the level of average inflation. $\hat{c}_u$ in (8) instead controls their beliefs about the effect of setting V equal to 0. In other words, $-\hat{c}_u$ represents the "natural" level of policy, i.e., the level of V that does not affect unemployment.[5] Notice that, without further assumptions, $\hat{c}_\pi$, $\hat{c}_u$, and $\hat{u}^N$ would not be separately identified in the policy econometric model. A discussion about this issue is postponed until the next subsection.

The outcome of policy-makers' optimal control problem is an optical plan $\{V_{s|t}\}_{s=t}^{\infty}$, although only $V_{t|t} \equiv V_t$ will actually be implemented:

$$V_t = g(\hat{\beta}_t)S_t, \tag{9}$$

where $\hat{\beta}_t$ represents the vector of values for the model's parameters that policy-makers treat as certainty-equivalents; $g(\hat{\beta}_t)$ is the standard solution of a linear-quadratic problem, obtained solving the corresponding Riccati equation. S_t meanwhile denotes the set of relevant state variables and beliefs about unobservable states of the economy. To be more concrete, assuming that all the lag polynomials have order one, $\hat{\beta}_t$ would be given by the vector $[\hat{c}_{\pi,t},\hat{\alpha}_{1,t},\hat{\alpha}_{2,t},\hat{\theta}_{1,t},\hat{\theta}_{2,t},\hat{c}_{u,t},\hat{\rho}_{1,t},\hat{\rho}_{2,t},\hat{u}^N_{t|t}]'$ and S_t by the vector $[1,\pi_t,\pi_{t-1},u_t - \hat{u}^N_{t|t},u_{t-1} - \hat{u}^N_{t-1|t},V_{t-1}]'$.

In relation to the optimal policy rule in (9), it is possible to

5. In the true model the "natural" level of policy is normalized to zero.

show (by simulations or analytically for a simplified version of the model) the following two very intuitive results. First, the lower the estimate of inflation persistence ($\hat{\alpha}(1)$), the lower the optimal reaction to inflation. This is due to the impression that inflation is mean-reverting and there is no need for anti-inflammatory policy. Second, (for a range of $\hat{\theta}$ corresponding to the estimated ones) the lower $\hat{\theta}(1)$, the lower the optimal reaction to inflation. That is, if policy-makers perceive a very costly inflation-unemployment trade-off, they will not be willing to accept higher unemployment for a limited relief from inflation. These two results will be crucial in the interpretation of the Great Inflation in the next section.

II.C. Learning

To implement the optimal rule and fix the value of the policy variable V_t, policy-makers must estimate the parameters of interest, which are the unobservables and the coefficients. While I relax this assumption in Primiceri [2004], in this paper I assume that policy-makers form their beliefs about the natural unemployment rate using univariate methods, i.e., they extract information about the natural rate, only looking at the behavior of unemployment. Observe that this is suboptimal as, conditional on the true model of the economy, better estimates could be obtained by exploiting the information contained not only in the unemployment rate, but also in the inflation rate. However, there are several reasons motivating this choice.

First, historical narrative evidence (for example, see DeLong [1997] and Romer and Romer [2002]) suggests that this is a realistic assumption for the behavior of past policy-makers. Even now, univariate algorithms are commonly used to define the potential of the economy, especially in the output gap and monetary policy literature (see, for instance, Orphanides and Van Norden [2001] or Taylor [1999]). Second, Staiger, Stock, and Watson [2001] show that the natural rate estimated formally using the Phillips curve approach is basically indistinguishable from the univariate trend in unemployment. The last reason is substantial. In fact, as mentioned above, $\hat{c}_\pi$, $\hat{c}_u$, and $\hat{u}^N$ are clearly not separately identified in equations (7) and (8). Therefore, I assume that policy-makers solve this identification problem by imposing the prior belief that, on average, unemployment is equal to its natural rate. This assumption provides a very natural way of estimating the natural rate, which is to use univariate algorithms on the series of unemployment, in order to isolate the low frequency component. Furthermore, observe that this assumption is not contradictory and respects the coherence of the policy-makers' model because, as will be shown in subsection II.D, it corresponds to a self-confirming equilibrium.

Conditional on their estimate of the natural rate of unemployment, policy-makers can estimate the model's coefficients using standard regression methods. Following a large part of the most recent literature (among others see Sargent [1999] or Williams [2003]), in the baseline specification of the model I assume that policy-makers update their beliefs using constant gain algorithms (CG). These algorithms allow updating beliefs discounting the past and giving more weight to recent data. Recent data are considered more informative possibly because of the suspicion of drift in the parameters.

As mentioned above, the estimation works in two steps. In the first step policy-makers obtain an estimate of the current value of the natural rate using the following updating formula:

$$\hat{u}^N_{t|t} = \hat{u}^N_{t-1|t-1} + g_N R^{-1}_{N,t-1}(u_t - \hat{u}^N_{t-1|t-1}), \tag{10}$$

$$R_{N,t} = R_{N,t-1} + g_N(1 - R_{N,t-1}). \tag{11}$$

Equation (10) states that the current estimate of the natural rate is obtained by updating the previous estimate according to the current realization of the unemployment rate. The weight given to the last observation depends on the gain (g_N) and the inverse of the variance of the regressor (the constant 1 in this case), which, in turn, is updated in equation (11).

In the second step policy-makers use their estimate of the natural rate to update their beliefs about the Phillips curve and aggregate demand coefficients:

$$\hat{\beta}^i_t = \hat{\beta}^i_{t-1} + gR^{-1}_{i,t-1}x^i_t(y^i_t - x^{i\prime}_t\hat{\beta}^i_{t-1}), \tag{12}$$

$$R_{i,t} = R_{i,t-1} + g(x^i_t x^{i\prime}_t - R_{i,t-1}), \quad i = \{\pi,u\}, \tag{13}$$

where

$$\hat{\beta}^\pi_t = [\hat{c}_{\pi,t},\hat{\alpha}_{1,t},\hat{\alpha}_{2,t},\hat{\theta}_{1,t},\hat{\theta}_{2,t}]'; \; y^\pi_t = \pi_t;$$
$$x^\pi_t = [1,\pi_{t-1},\pi_{t-2},u_{t-1} - \hat{u}^N_{t-1|t},u_{t-2} - \hat{u}^N_{t-2|t}];$$
$$\hat{\beta}^u_t = [\hat{c}_{u,t},\hat{\rho}_{1,t},\hat{\rho}_{2,t}]'; \; y^u_t = u_t - \hat{u}^N_{t-1|t} - V_{t-1};$$
$$x^u_t = [1,u_{t-1} - \hat{u}^N_{t-1|t},u_{t-2} - \hat{u}^N_{t-2|t}].$$

Equations (12) and (13) update beliefs with a mechanism similar to the one illustrated for equations (10) and (11).[6]

Observe that I allow for the possibility of different gain parameters in the algorithms for the estimation of the natural rate and the coefficients (respectively, g_N and g). The gain parameters control the rate at which new information affects beliefs. If g and g_N were decreasing and equal to $1/(t - 1)$, equations (10), (11), (12), and (13) would be recursive representations of ordinary least squares estimates (if properly initialized).

As robustness checks, I also consider the cases in which policy-makers form estimates of the natural rate using a moving average and estimates of the coefficients by ordinary least squares (OLS) or discounted least squares (DLS), a weighted least squares method with weight Δ^{t-2} to time s observation (where t is the time period of the most recent data and $\Delta < 1$ is a discount factor).

II.D. Equilibrium and Steady State

As is standard in most of the recent literature on learning, I focus on the concept of self-confirming equilibria.[7] In period t, policy-makers form beliefs about the model's parameters ($\hat{\beta}_t$). Their beliefs imply an optimal value for the policy variable V_t, which, in turn, affects the stochastic data-generating process and, ultimately, next period's beliefs about the parameters β. This defines a map from today's beliefs to tomorrow's beliefs. A fixed point of this map is a self-confirming equilibrium. In other words, a self-confirming equilibrium is a situation in which policy-makers' beliefs about β are expected not to change with the new vintage of data. The Appendix gives a formal definition of the self-confirming equilibrium, while the downloadable appendix derives the model's self-confirming equilibrium for the baseline case in which beliefs are formed using the CG algorithm.[8]

I define the model's steady state as the unconditional mean of the stationary stochastic process for the vector $[\pi_t, u_t, V_t, u_t^N]$ in a self-confirming equilibrium. Observe that, in steady state, (5)

6. I assume that policy-makers approximate $\hat{u}^N_{t-1|t}$ and $\hat{u}^N_{t-2|t}$ with their last estimate of the current level of the natural rate, $\hat{u}^N_{t|t}$. This is a simplification to reduce computational time. The estimates of the natural unemployment evolve so smoothly that this assumption does not make any difference for the results.

7. For a formal treatment of the issue, see Sargent [1999], Evans and Honkapohja [2001], and Williams [2003].

8. The appendix is available upon request and can be downloaded on the web site of the author at http://www.faculty.econ.northwestern.edu/faculty/primiceri.

implies that $u_t = u^*$. Consequently, $V_t = 0$ follows from (2). Finally, (9) implicitly defines the steady state inflation as a function of the equilibrium beliefs.

As an example and for simplicity, consider the intuitive case of a constant natural unemployment rate.[9] Notice that, if $k = 1$, the steady state inflation is just the inflation target π^*. In other words, if policy-makers do not wish to push unemployment below the natural rate, the outcome is the optimal one in which unemployment is at the natural level and inflation at the target. If $0 \leq k < 1$ instead, the steady state inflation will be higher. As it will be clear later, the data favor a model with a limited amount of inflation bias, due to the fact that postwar policy-makers did not seem to have an excessively low unemployment target.

III. Interpreting the Great Inflation

The Great Inflation refers to the high inflation and unemployment episode of the 1960s, 1970s, and early 1980s (Figure I). The model of the previous section provides a useful and powerful tool for the interpretation of this long and important episode of U. S. recent economic history.

I begin the imaginary simulation in 1960. Figure II plots real-time estimates of the natural rate of unemployment, inflation persistence in the Phillips curve, and the slope of the Phillips curve, starting in 1960 and formed using data from 1948. These represent measures of real-time policy-makers' beliefs affecting the choice of the policy variable V. The persistence of inflation is measured by the sum of coefficients on lagged inflation, i.e., $\hat{\alpha}(1)$ in (7). The slope of the Phillips curve is measured as the sum of coefficients on unemployment deviations from the natural rate, i.e., $-\hat{\theta}(1)$ in (7). Finally, these estimates are constructed using the baseline, constant gain learning algorithm of subsection II.C, but their qualitative behavior is very robust to the alternative specifications of the learning algorithm.

III.A. The Period of Overoptimism

To start, notice that in the first part of the sample policy-makers' estimates of the natural rate of unemployment were

9. In the case of a constant natural rate of unemployment, it is easy to check that, in the self-confirming equilibrium, beliefs about the model's coefficients coincide with the true values. As shown in the Appendix, when $\text{var}(u_t^N)$ is bigger than zero equilibrium beliefs about the model's parameters do not necessarily coincide with the true parameters of the model, but can be arbitrarily close.

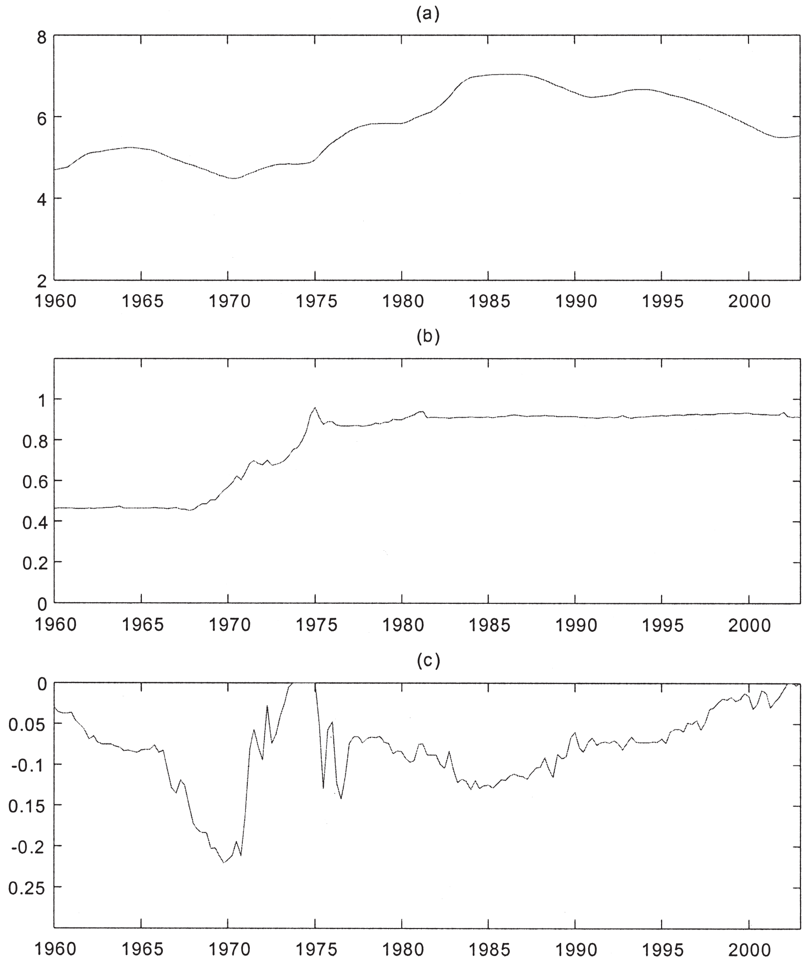

FIGURE II
Evolution of Policy-makers' Beliefs about: (a) the Natural Rate of Unemployment; (b) the Persistence of Inflation in the Phillips Curve; (c) the Slope of the Phillips Curve

between 4 percent and 5 percent. These are low numbers, compared with our current estimates of the level of the natural rate in the 1960s and the first part of the 1970s.[10]

10. For example, compare Figure IIa to the model-based, smoothed estimates of the natural rate of unemployment plotted in Figure III.

This erroneous belief that the natural rate was so low led to overexpansionary monetary and fiscal policies. However, while this can explain why inflation started rising in the early 1960s, it is not sufficient to explain why rational policy-makers let inflation increase so much and for such a long period of time. What is key to rationalize policy-makers' behavior in the 1960s and 1970s, is realizing that they were uncertain not only about the value of the natural rate, but also about the value of all remaining parameters of their model. In particular, observe that the real-time estimate of inflation persistence ($\alpha(1)$) in the early 1960s was approximately equal to 0.5 (Figure IIb).

According to the model, a low estimate of $\hat{\alpha}(1)$ implies a low reaction to inflation, due to the erroneous belief that inflation is rather stationary around some mean. This explains the passive behavior of policy-makers in the 1960s. I will refer to this period as the *overoptimism* period, during which inflation was perceived as stationary, the natural rate of unemployment as low, and the optimal policy was keeping unemployment close to the estimated natural rate, without much concern for the accelerating inflation.

By now, it is not controversial that policy-makers' real-time estimates of the natural rate, the persistence of inflation, and the inflation-unemployment, long-run trade-off were too optimistic in that period (see, for example, Orphanides and Williams [2002], DeLong [1997], Mayer [1999], and Romer and Romer [2002]).

III.B. The Period of Overpessimism

Slowing something changed. In fact, as suggested by the model and confirmed by Figure IIb, the estimates of $\alpha(1)$ were slowly revised upwards, toward the true value of 1.

However, while this would imply a reinforcement of the policy reaction to inflation, policy reaction remained low because of the following perverse mechanism: policy-makers noticed that pushing unemployment above the *underestimated* natural rate did not provide any relief from inflation. As a consequence, they revised their beliefs about the slope of the Phillips curve toward zero ($\hat{\theta}$ decreases in the early 1970s, as shown in Figure IIc). As implied by the model, this reduced the strength of policy reaction to inflation. In other words, even after the overoptimism period, policy-makers kept reacting weakly to inflation, this time because they perceived a very costly inflation-unemployment trade-off. Okun [1978] provides clear evidence that this was actually the case. In fact, he surveys a number of papers written in the 1970s by important economists and concludes that "the average estimate of the cost of 1 point reduction in the basic inflation rate is 10 percent of a year's GNP" [p. 348]. Another example that the perceived sacrifice ratio was very high is the following statement by the *Economic Report of the President* [EROP]: "When inflation failed to respond significantly to macroeconomic policy, a 90-day wage and price freeze was announced on August 15, 1971; it was followed by a period of mandatory wage and price controls" [EROP 1979, pp. 54–55]. Commenting on the current economic conditions, the 1972 EROP further referred to a: "tendency to an unsatisfactorily high rate of inflation which persists over a long period of time and is impervious to variations in the rate of unemployment, so that the tendency cannot be eradicated by any feasible acceptance of unemployment" [EROP 1972, p. 113]. Even in 1979, the EROP wrote: "We will not try to wring inflation out of our economic system by pursuing policies designed to bring about a recession. That course of action . . . would be ineffective. Twice in the past decade inflation has accelerated and a recession has followed, but each recession brought only limited relief from inflation" [EROP 1979, p. 7].

I will refer to this period as the *overpessimism* period, during which policy did not fight inflation because policy-makers "did not believe it would work at an acceptable cost" [DeLong 1997, p. 264]. The *overpessimism* period is successive to the *overoptimism* one and accounts for the long duration of the hump-shaped episode.

III.C. The Disinflation

In the meantime, policy-makers' estimate of inflation persistence in the Phillips curve had been updated toward the true value of one. In this situation, even small changes of the policy variable are perceived to have long-lasting consequences on the inflation rate. Hence, the model predicts that small updates of the estimate of the slope of the Phillips curve have large effects on the strength of the policy reaction. Therefore, the episode of high inflation ended after a proper revision of the estimate of the slope of the Phillips curve. This happened because of a sequence of new exogenous shocks, which caused updates of $\hat{\theta}$ toward the self-confirming equilibrium. When the bias of $\hat{\theta}$ decreased and the perceived inflation-unemployment trade-off improved, policy-makers reacted strongly to high inflation, because they finally had a model of the economy that was approximately correct.

Consequently, unemployment was pushed quickly way above the estimated natural rate. The sharp disinflation was the result of this prompt and strong action. Policy maintained a high unemployment rate until inflation came back under control. At that point unemployment slowly returned to levels close to the natural rate.[11]

Notice that the model's predictions match the stylized facts very well. In fact, not only is the model able to account for the dimension and the duration of the episode, but also is it able to explain why the disinflation period was shorter than the run-up period and why unemployment increased and decreased during the 1970s and 1980s, lagging behind inflation.

It is important to stress that this paper offers an explanation of the Volcker disinflation, which is not based on a sudden change of policy-makers' preferences in the late 1970s. Here, instead, the disinflation occurs when the perceived inflation-unemployment trade-off becomes favorable, relative to the level of inflation.

III.D. The Cost of Disinflation

The fact that the disinflation is delayed due to the perceived high sacrifice ratio represents an important difference between this paper and Sargent [1999]. In Sargent [1999] policy-makers believe that policy is able to affect real activity only by directly controlling inflation. Therefore, when the correlation between inflation and unemployment approaches zero (as in the early 1970s), for Sargent's [1999] policy-makers this represents a unique opportunity to disinflate, since it can be done at no cost in terms of real activity. This does not seem to correspond to what we observe in the data.[12]

Like this paper, Cogley and Sargent [2004] also interpret the rise and fall of inflation as the result of a learning process of U. S. policy-makers. However, the policy-makers in their papers con-

11. Observe that toward the end of the sample the slope of the Phillips curve approaches zero again. This is due to the fact that the CG learning model discounts the past and gives more weight to recent data, creating the possibility of temporary deviations from the self-confirming equilibrium [Williams 2003]. This should not be of any concern for the stability of inflation and unemployment toward the end of the sample. In fact, it happens during a period in which the perceived natural rate is relatively close to the actual one and, especially, in a period in which the estimated persistence is close to unity.

12. Sargent, Williams, and Zha [2004] use a model that is very similar to Sargent [1999] and seem to be able to reconcile the prediction of the model with the observed data in the 1970s thanks to a very volatile evolution of policy-makers' beliefs.

sider the prescriptions of three policy models, and the delayed disinflation is explained by their concern for robustness. Although I do not deny that this might be an important part of the story, here I move in another direction. In fact, I show that a perfect explanation of the behavior of inflation can be obtained when policy is based simply on one model of the economy, if only one is willing to assume that policy-makers in the 1960s and 1970s regarded real activity and not inflation under their control. Although they do not provide conclusive evidence, the quotes of subsection III.B suggest that this was actually the case, and building a model with this feature constitutes one important innovation of this paper.

Another crucial difference between this paper and Cogley and Sargent [2004] (as well as Sargent [1999] or Sargent, Williams, and Zha [2004]) is the fact that, as a "true" structure of the economy, I use a reduced-form new Keynesian model, i.e., a model in which deviations of real activity from potential affect inflation. This allows me to explain the behavior of unemployment during the Great Inflation. The use of a "true" model of the economy similar to Lucas [1972] and Sargent [1973] prevents Cogley and Sargent [2004], Sargent [1999], and Sargent, Williams, and Zha [2004] from offering any explanation for the hump-shaped behavior of unemployment.

IV. Empirical Evidence

This section presents empirical evidence supporting the model of Section II and the dynamics illustrated in Section III.

I estimate the model by maximum likelihood methods, over a sample period running from 1960:I to 2002:IV, using quarterly data on inflation and unemployment.[13] I let policy-makers estimate the approximate model and, consequently, choose V in every period. Putting the model in state space form, the likelihood can be computed using the Kalman filter (see the Appendix). The likelihood is maximized with respect to nine parameters, $[\alpha_1,\theta_1,\theta_2,\rho_1,\rho_2,k,\phi,\sigma_\varepsilon^2,\sigma_\eta^2]$, while I fix $\delta = 0.99$, $\pi^* = 2$, $\lambda = 1$, $u^* = 6$, $\gamma = 0.99$, $\sigma_\tau^2 = 0.0199$. Fixing δ is standard practice. I fix $\pi^* = 2$ because this number is close to the estimates of the

13. As in the rest of the paper, inflation is measured by the annualized quarterly growth rate of the GDP deflator and unemployment by quarterly averages of the monthly civilian unemployment rate.

inflation target level for the post-Volcker era (see, for instance, Bullard and Eusepi [2003], Schorfheide [2003], or Favero and Rovelli [2003]). However, different from these previous studies, there is no exogenous switch in the level of the inflation target in my model. λ is set to 1 to be consistent with some previous studies (for example, Sims [1988] and Sargent [1999]).[14] Finally, for the coefficients of the exogenous process driving the natural rate, $u^* = 6$ is chosen to match the average of unemployment during the sample period. γ is fixed at 0.99 and σ_τ^2 at 0.0199 to impose the prior belief that the natural rate is smoother than unemployment itself. Notice that the value of γ and σ_τ^2 imply an unconditional variance of 1 for the natural rate. Furthermore, in the case of the constant gain learning, g is set to 0.015, and g_N to 0.03. Observe that the constant gain for the estimation of the natural rate of unemployment is higher than the one for the estimation of the parameters. This captures the fact that policy-makers expect the natural rate to drift more than the model's coefficients. I calibrate the initial beliefs in the most natural way, that is using the actual data from 1948 to 1960 (assuming that policy was at its natural level between 1948 and 1960).[15] This procedure results in the following set of initial beliefs in 1960: $[\hat{c}_\pi, \hat{\alpha}_1, \hat{\alpha}_2, \hat{\theta}_1, \hat{\theta}_2, \hat{c}_u, \hat{\rho}_1, \hat{\rho}_2, \hat{u}^N] = [1.156, 0.330, 0.131, -0.914, 0.885, 0.012, 1.536, -0.717, 4.701]$.

IV.A. Estimation Results and Model's Fit

The point estimates and the standard errors of the free coefficients are reported in Table I for the three specifications of the learning algorithm. Five results stand out. First, the estimates obtained using different assumptions for the policy-makers' learning process are very similar to each other. Second, the estimate of ϕ, the smoothing coefficient in the policy loss function, might appear as too high. However, once movements in the policy variable V are interpreted in terms of deviations of unemployment from the natural rate, the size of ϕ is not a puzzle anymore.[16] Third, all the other coefficients have reasonable sign and

14. Interestingly, if λ is treated as a free parameter in the estimation procedure, the point estimate is 0.99, with a standard error of 0.36.

15. I used the DLS algorithm with discount rate $\Delta = 1 - 1/120$.

16. For example, consider a permanent unitary increase in the level of V_t. This would create a permanent deviation of unemployment from the natural rate equal to $1/(1 - \rho(1))$. Therefore, the term ϕV_t^2 in the loss function could be expressed in terms of deviations of unemployment from the target as $\phi(1 - \rho(1))^2(u_t - \hat{u}_t^N)^2$, where the weight becomes $\phi(1 - \rho(1))^2$. If unemployment is very

TABLE I
MAXIMUM LIKELIHOOD ESTIMATES OF THE MODEL'S PARAMETERS

Coefficients	CG	OLS	DLS
α_1	0.707	0.711	0.707
	(0.074)	(0.074)	(0.073)
θ_1	−1.053	−1.021	−1.057
	(0.292)	(0.290)	(0.291)
θ_2	0.928	0.903	0.943
	(0.289)	(0.287)	(0.289)
ρ_1	1.661	1.756	1.640
	(0.057)	(0.065)	(0.056)
ρ_2	−0.737	−0.779	−0.719
	(0.057)	(0.060)	(0.056)
σ_ε^2	1.033	1041	1.033
	(0.113)	(0.113)	(0.109)
σ_η^2	0.036	0.036	0.035
	(0.006)	(0.006)	(0.006)
ϕ	2131	475.5	1902
	(1570)	(273.9)	(1119)
k	0.872	0.960	0.809
	(0.026)	(0.014)	(0.032)

CG: model with constant gain learning; DLS: model with discounted least squares learning; OLS: model with ordinary least squares learning. Standard errors are in parentheses.

size. Fourth, the estimate of k, the parameter that affects the unemployment target in the loss function (6), is close to unity, casting doubt on the inflationary bias story that I mentioned in the introduction. Fifth, formal measures of fit (like the Bayesian information criterion or the marginal likelihood) favor the learning model over unrestricted reference models like vector autoregressions (this result is demonstrated in Primiceri [2005b]).

Figure III plots the smoothed estimate of the natural rate of unemployment, which resembles previous estimates in the literature (Staiger, Stock, and Watson [2001] or Gordon [1997]).

Figure IV plots the evolution over time of the model's policy variable V. A measure of the ex post real rate of interest (rescaled)[17] is reported for comparison. Notice the similarities between the two series, especially in the second part of the sam-

persistent, $\rho(1)$ will be close to 1 and $\phi(1 - \rho(1))^2$ will be similar to the smoothing coefficient in other papers.

17. The real rate of interest is computed as the federal funds rate minus the quarterly inflation rate averaged over the last four quarters.

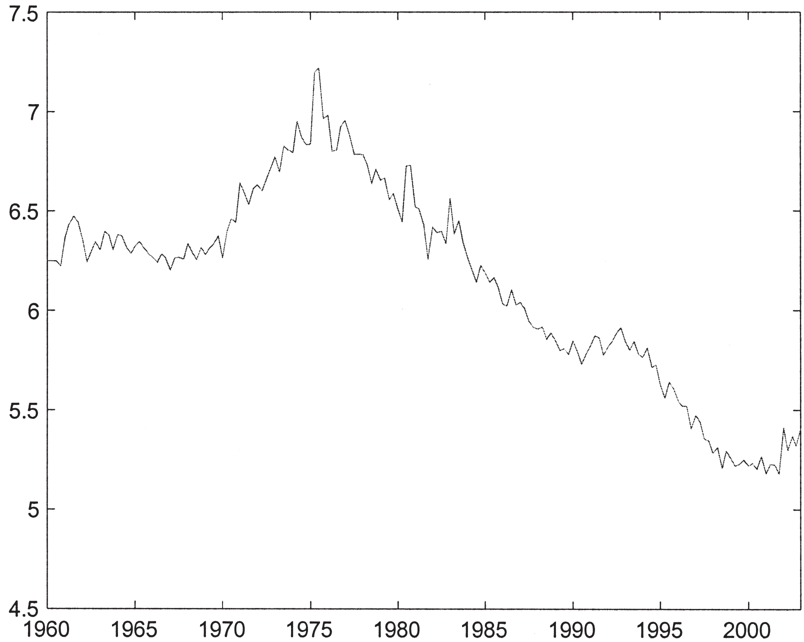

FIGURE III
Smoothed Estimates of the Natural Rate of Unemployment

ple. In addition, Figure V plots the long-run response to inflation in the time-varying policy reaction function. While the scale is not directly comparable to the response to inflation in a Taylor rule, the behavior of the series reflects perfectly well the empirical and anecdotal evidence about the Fed's stronger reaction to inflation in the second part of the postwar sample (see, for example, Clarida, Gali, and Gertler [2000] or Judd and Rudebusch [1998]). These results are remarkable, if we consider that the time series for V has been obtained without any information related to the interest rate.

IV.B. Simulations

This subsection considers quantitative simulations of the model in the case of the benchmark (CG) specification. The purpose of these simulations is twofold. First, they show that the model produces a pronounced, prolonged and asymmetric hump-shaped behavior of inflation and unemployment. In addition,

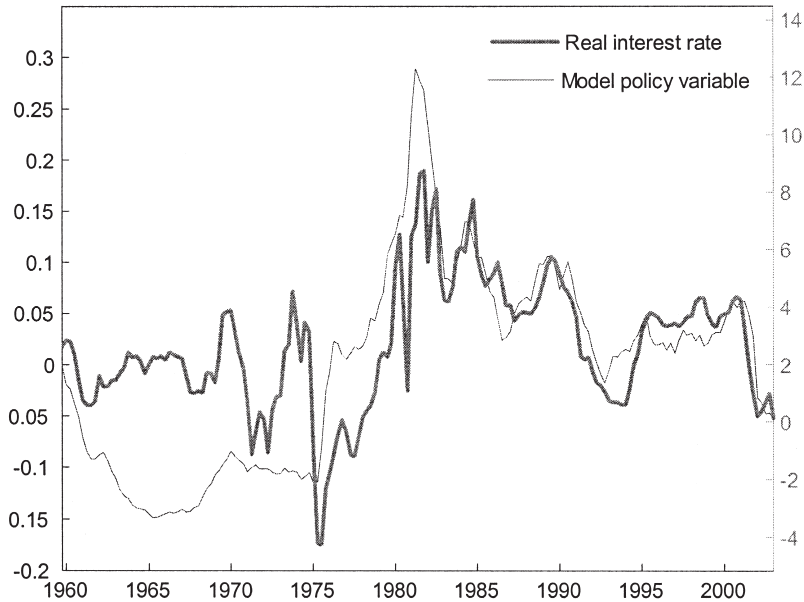

FIGURE IV
Model's Policy Variable and Real Rate of Interest (Right Axis)

these simulations highlight that the mismeasurement of the natural rate of unemployment alone is not sufficient to reproduce this kind of hump-shaped behavior.

In order to do so, I conduct the following exercise. I start in 1960:I, assuming that data on inflation and unemployment are the actual data from 1948:I to 1959:IV. In 1960:I, policy-makers optimize their objective function on the basis of the current estimates and fix the value of V for the current period. Unemployment and inflation in 1960:II are determined through the true Phillips curve and aggregate demand equations, (5) and (2). In the next period, policy-makers reestimate their approximate model and choose the new value for the policy variable. With this mechanism I simulate 42 years of quarterly data, up to 2002. In the simulations I assume that the true value of the model's parameters are the values estimated in the previous subsection and reported in the first column of Table I. Also as the "true" natural rate of unemployment I use the smoothed estimate plotted in Figure III. Finally, I perform the simulations generating sequences of *i.i.d.* random innovations with mean zero and variance corresponding to the estimated value reported in Table I.

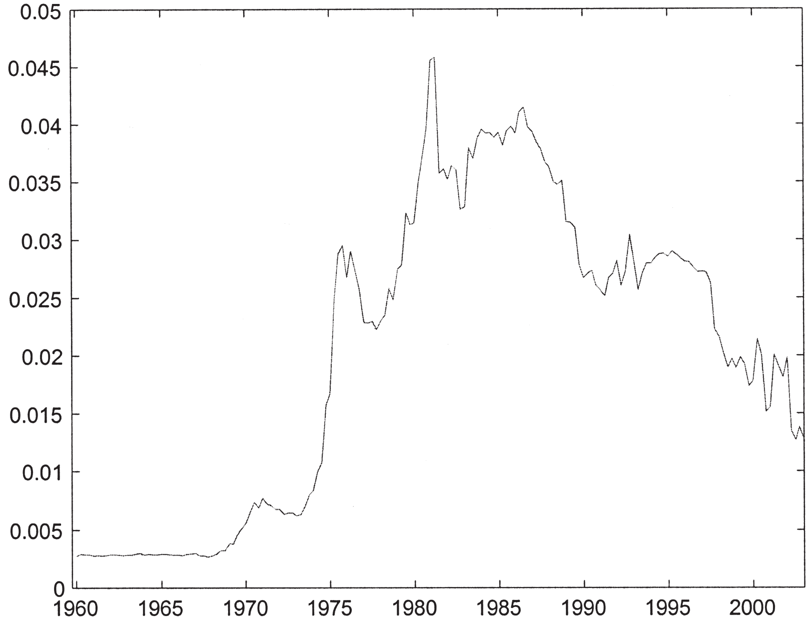

FIGURE V
Response to Inflation in the Time-Varying Policy Reaction Function Implied by the Model

I perform 3000 simulations using identical initial conditions for policy-makers' beliefs in 1960 (the ones reported in Section IV), but different series of exogenous shocks. The main results are summarized in Figure VI. Figures VIa–VId graph the empirical distribution of four objects: the maximum level reached by the inflation rate between 1960 and 2002 ($\max(\pi)$); the time period in which inflation reaches its maximum level (t_π^*); the maximum level reached by the unemployment rate between 1960 and 2002 ($\max(u)$); the difference (expressed in years) between the time period in which unemployment peaks and the time period in which inflation peaks ($t_u^* - t_\pi^*$). The scatter-plots of Figure VIe and VIf are meant to illustrate two bivariate relations: the relation between peak time and the peak level of inflation; the relation between the peak level of unemployment and inflation. Overall, Figure VI makes clear that the model reproduces the main characteristics of the Great Inflation remarkably well. In particular, the model fully captures the dimension, the duration of the high inflation episode, and the fact that unemployment peaks after inflation.

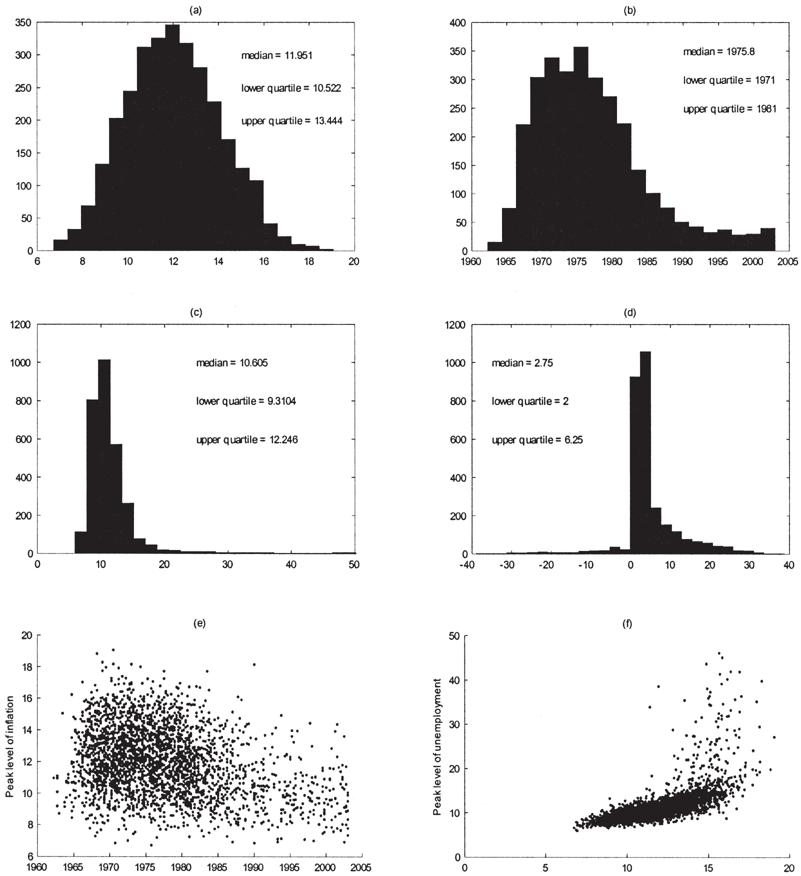

FIGURE VI
Simulation Results for the Benchmark Model

Empirical distribution of: (a) $\max(\pi)$, (b) t^*_π, (c) $\max(u)$, and (d) $t^*_u - t^*_\pi$. Scatter-plot of the relation between (e) t^*_π and $\max(\pi)$ and (f) $\max(\pi)$ and $\max(u)$. ($\max(\pi)$ and t^*_π stand, respectively, for the peak level and the peak time of inflation, while $\max(u)$ and t^*_u stand for the peak level and the peak time of unemployment).

Showing that, on average, the simulated time paths exhibit a rapid disinflation is less straightforward, because simply averaging the simulated time paths would not preserve the typical shape. To solve this problem, I compute the average path, but only after rescaling the horizontal and vertical axis in every simulation, to make them peak at the same time and at the same

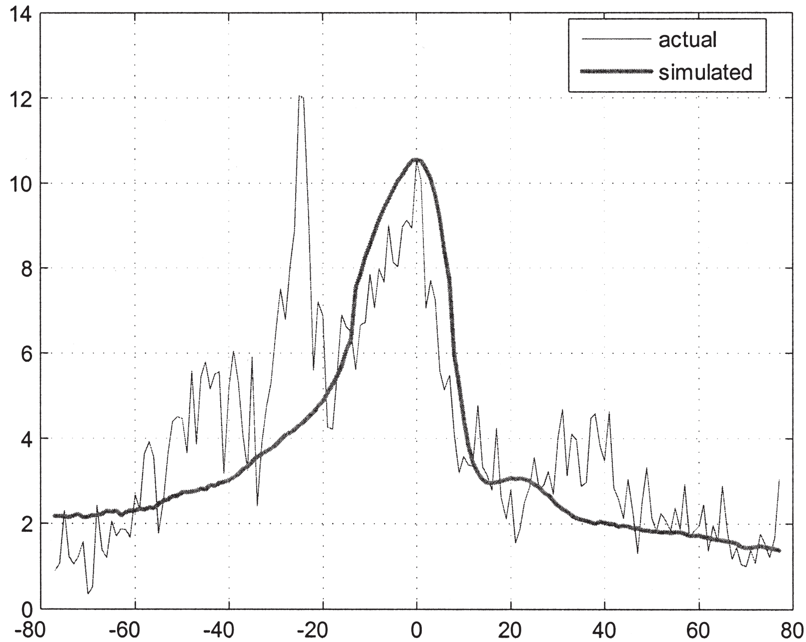

FIGURE VII
Actual Data and Average of the Simulated Inflation Paths around the Peak Time (Time Expressed in Quarters on the Horizontal Axis)

level.[18] The result is plotted in Figure VII, where the peak time of the average inflation path is normalized to zero and the peak value to the peak level of actual inflation in 1981. Actual inflation is also reported for comparison. The striking feature of Figure VII is that the average of the simulated paths captures perfectly the so-called Volcker disinflation, that many macro models have difficulties in addressing.

Figure VIIIa plots a simulation of the behavior of inflation and unemployment, when the standard deviation of the shocks to the Phillips curve and the aggregate demand are chosen as small as possible and are fixed, respectively, at 0 and 0.005.[19] This is

18. In order to determine the peak time of inflation in a robust way, I compute a five-year moving average for every simulated path and select the point in time in which the resulting smooth series reaches the maximum.

19. Two observations are necessary at this point. First, the standard deviation of the shocks to the aggregate demand cannot be set to zero because some random variation in the regressors of the Phillips curve is necessary for a mean-

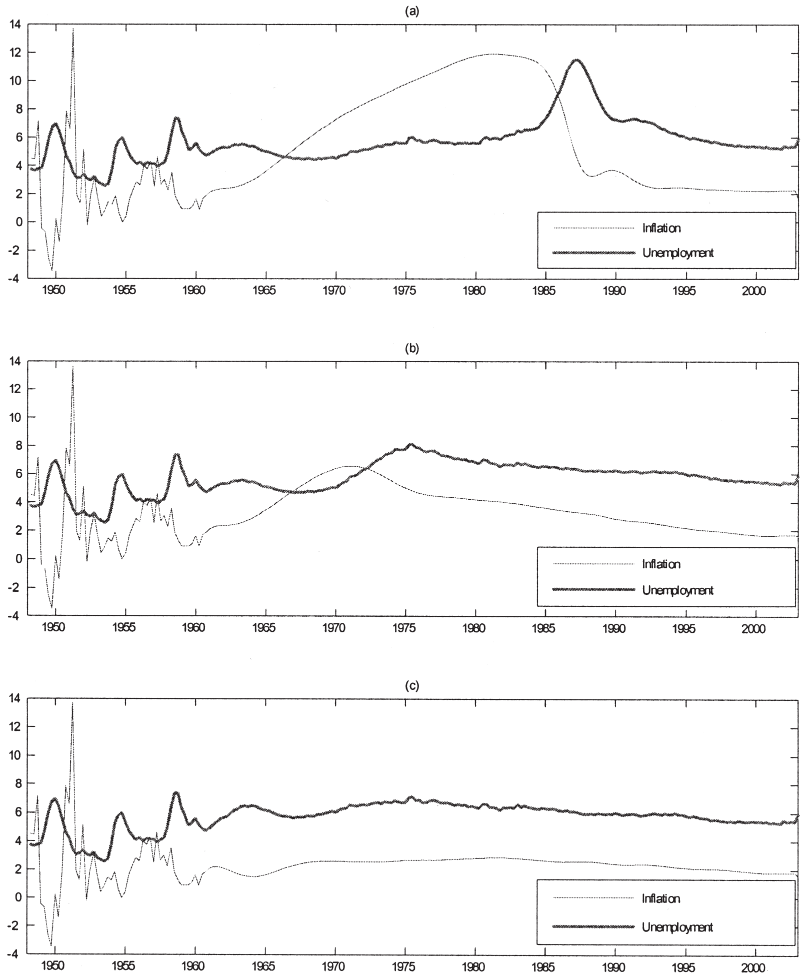

FIGURE VIII

Simulation of the Inflation and Unemployment Behavior under a Scenario of Low Volatility of the Exogenous Disturbances

(a) Simulation for the baseline constant gain learning model; (b) counterfactual simulation under the assumption that policy-makers know the slope of the Phillips curve; (c) counterfactual simulation under the assumption that policy-makers know all the parameters of the Phillips curve except for the natural rate of unemployment.

ingful learning dynamics and the convergence to the self-confirming equilibrium. Second, the simulations with low or zero variance shocks all look exactly the same except for the time period in which inflation (and, of course, unemployment) peaks.

clearly improper, since the model is nonlinear and the size of the shocks might affect the speed of the learning process. Nevertheless, if we keep this in mind, this simulation shows that the model can capture perfectly well the low frequency behavior of inflation and unemployment, even with small exogenous shocks. This exercise further stresses the role of initial beliefs, which play a more prominent role than the exogenous shocks in the generation of these peculiar dynamics. This differs from Sargent, Williams, and Zha [2004].

Figure VIIIa is also very interesting for the behavior of the simulated path of inflation in the last part of the sample. In the 1990s the "true" series of the natural rate of unemployment exhibits a sharp decline (corresponding to the advent of the so-called "New Economy"), which is recognized only gradually by policy-makers in the simulation. Nevertheless, since the 1990s policy-makers have approximately learned the true values of the long- and short-run slopes of the Phillips curve, they are able to prevent inflation from falling the undesirably low levels. This matches very well the actual behavior of inflation in the last decade.

To stress even more the importance of the misperception about the coefficients of the Phillips curve in the 1960s and 1970s, Figures VIIIb and VIIIc plot the results of counterfactual simulation exercises. Here I use the same sequence of random shocks used to generate Figure VIIIa, but I change some of the values of the parameters of the model. In the simulation of Figure VIIIb, I assume that policy-makers know the exact value of the slope of the Phillips curve. However, they are uncertain about the natural rate and inflation persistence in the Phillips curve, and they have to estimate them. It is evident that the high inflation episode would not have lasted as long and that the rapid disinflation would have disappeared. Instead, in Figure VIIIc, I assume that policy-makers have the correct estimate of the parameters of the Phillips curve, except for the natural rate, which is estimated in the usual way. It is clear that, if this had been the case, inflation would have increased much less than it did. Indeed, this graph does not exhibit any sizable low frequency behavior.

In order to shed some light on the model's implications for the future path of inflation, I performed 1000 simulations for the next 100 years. In these simulations over the period from 2003 to 2102, policy-makers' estimates of inflation persistence never reach the low levels of the 1960s, which means that normal supply and demand shocks do not seem to have a major effect on policy-makers' estimates of the Phillips curve coefficients when enough data are available for the estimation. As a consequence of this, in all these forward simulations, if and when inflation goes up, it remains high only for a short period of time because, different from the Great Inflation, the propagation mechanism through learning is absent.

V. Why Did Inflation Rise?

In the previous sections I have argued that policy-makers' mistakes in the estimation of the natural rate of unemployment can only explain why inflation started to increase in the early 1960s. Observe that mistakes in the estimation of the natural rate in real time are, to some extent, unavoidable (see, for example, Orphanides and Van Norden [2001]). This is because the natural rate is intrinsically a time-varying entity, due to a number of factors like demographics, changes in productivity growth, or labor market conditions (for an overview, see Ball and Mankiw [2002]).

On the other hand, the optimistic view about the natural rate is not enough to understand why rational policy-makers let inflation rise for more than fifteen years. In fact, I showed that in the 1960s policy-makers did not fight inflation strongly enough because they underestimated the persistence of inflation in the Phillips curve. This induced the peculiar dynamics described in Section III.

Of course, a fundamental question is why policy-makers started out with such downward biased beliefs about the degree of the persistence of inflation in the Phillips curve ($\alpha(1)$) in the 1960s? The answer to this question is very simple and natural: because these beliefs were perfectly consistent with the available data prior to 1960. Observe that this is true not only if we look at data between 1948 and 1960 (like this paper does to calibrate initial beliefs), but also if we look further back in the past. For example, Christiano and Fitzgerald [2003] provide unambiguous evidence that all data between 1900 and 1960 appeared consistent with a stable long-run trade-off between inflation and unemployment. Similarly, Barsky [1987] uses data from 1890 to formally show that strong inflation persistence emerged only around 1960. In other words, there was basically no way for adaptive policy-makers learning from the past to anticipate the high degree of persistence of the last decades.

There are obviously many possible reasons why the properties of the inflation-unemployment process might have changed so drastically in the postwar period. One conjecture is that the different nature of the data is related to a change in monetary regimes like, for instance, the movement away from the Gold Standard and Bretton Woods (for an overview, see Bordo [1993]). This does not necessarily imply that inflation rose because policy-makers abandoned the commitment technology provided the fixed exchange rate regimes (like, for instance, in Bordo and Kydland [1995]). The interpretation provided in this paper is instead that inflation rose because policy-makers were simply slow to learn how to conduct policy under a new regime.

VI. Concluding Remarks

This paper presents and estimates a model of inflation-unemployment dynamics when policy-makers have imperfect information about the structure of the economy. The main result of the paper is that policy-makers' learning dynamics can perfectly account for the rise and fall of U. S. inflation over the last 40 years.

This result is robust to several sensitivity checks and extensions of the main framework, which, in order to save space, are not reported here but can be found in Primiceri [2005b]. These extensions include modifying the "true" model of the economy to consider forward-looking, rational private agents; controlling for potential breaks in policy-makers' preferences about the inflation target, the unemployment target, and their relative weight over the last 40 years; controlling for stochastic volatility of the exogenous, nonpolicy shocks to account for the role of oil price shocks and, in general, for the high variance of the innovations in the 1970s.

Given the empirical support, the model can be used to evaluate the possibility that episodes similar to the Great Inflation could happen again in the future. In this respect, the conclusion of the paper is more optimistic than alternative theories. In this model, in fact, high inflation episodes do not occur as the consequence of the mismeasurement of the natural rate of unemployment only [Orphanides 2000] or as a result of policy-makers' lack of commitment to low inflation (for example, Sargent [1999]). High inflation is the consequence of the unlikely combination of two factors. As mentioned above, one of these two factors is the mismeasurement of the natural rate, which, to some extent, is unavoidable. However, the serious underestimation of the persistence of inflation in the Phillips curve seems to be much more uncommon and appears more related to special circumstances, such as structural breaks in the true model of the economy.

Appendix: Self-Confirming Equilibrium

This appendix formally defines a self-confirming equilibrium of the model in the case of constant gain learning. Let y_t^π, y_t^u, x_t^π, x_t^u, $\hat{\beta}^\pi$, and $\hat{\beta}^u$ be the same objects defined in subsection II.C. I follow Sargent [1999] in defining a self-confirming equilibrium in this framework:

Definition 1. A self-confirming equilibrium is a set of policymakers' beliefs about the models' parameters $\hat{\beta} \equiv [\hat{\beta}^\pi, \hat{\beta}^u, \hat{u}^N]$, a fixed optical policy rule $g(\hat{\beta})$, and an associated stationary stochastic process for the vector $[\pi_t, u_t, V_t, u_t^N]$ such that (a) $\hat{u}^N$, $\hat{\beta}^\pi$ and $\hat{\beta}^u$ satisfy

$$E[u_t - \hat{u}^N] = 0 \tag{14}$$

$$E[x_t^i(y_t^i - x_t^{i\prime}\hat{\beta}^i)] = 0, \quad i = \{\pi, u\}, \tag{15}$$

where the expectations are taken with respect to the probability distribution generated by (5), (2), (3), and (9); (b) the vector $[\pi_t, u_t, V_t, u_t^N]$ is generated by the stationary stochastic process implied by (5), (2), (3), and (9).

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