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A CONSTANT GAIN LEARNING FRAMEWORK TO UNDERSTAND THE BEHAVIOUR OF US INFLATION AND UNEMPLOYMENT IN THE 2ND HALF OF 20TH CENTURY

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Abstract

We build an adaptive learning model where policymakers use constant gain learning algorithm to update their knowledge/estimates of the model every time period. The optimal policy is enacted every time period by policymakers assuming their current knowledge of the model to be perfect. This framework is used to study the behavior of post war US inflation and unemployment. The model accurately explains the Great Inflation- while the rational expectations equilibrium is characterized by low inflation, learning leads to disequilibrium dynamics when initial knowledge of the model is incorrect. Specifically, under estimation of the natural rate, persistence of inflation and slope of Phillips Curve by policymakers explains the high and persistent nature of inflation from 1963 to 1980. The convergence of learning to rational expectations equilibrium explains the subsequent disinflation. We further show that, within the learning framework, policymakers exposed themselves to the time consistency problem. Between 1960-1979, they pursued an artificially low target for the unemployment rate. Since Volcker, policymakers have accepted the natural rate hypothesis and hence have avoided the inflationary bias arising from time consistency problem.

Key words: *natural rate of unemployment, persistence, stagflation, time inconsistency, state space, kalman filter, maximum likelihood estimation, constant gain (CG) learning*

JEL Codes: *E32, E37, E58, E52*

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INTRODUCTION

The period 1960-1985 has been of significant interest to policymakers and academicians alike. At its peak, inflation[1] was 12% while unemployment was 10.6%. Table 1 presents preliminary descriptive statistics about quarterly inflation and unemployment between 1960-2002. Table 1 is accompanied by Figure 1.

Table 1: Inflation and Unemployment: Mean and Volatility

Time Period	Inflation: Average	Inflation: Variance	Unemployment: Average	Unemployment: Variance
1960:Q1-1979Q2	4.4	8.47	5.49	1.8
1979:Q3-2002:Q4	3.2	4.73	6.3	2.28
1960:Q1-2002:Q4	3.43	6.87	5.63	2.4

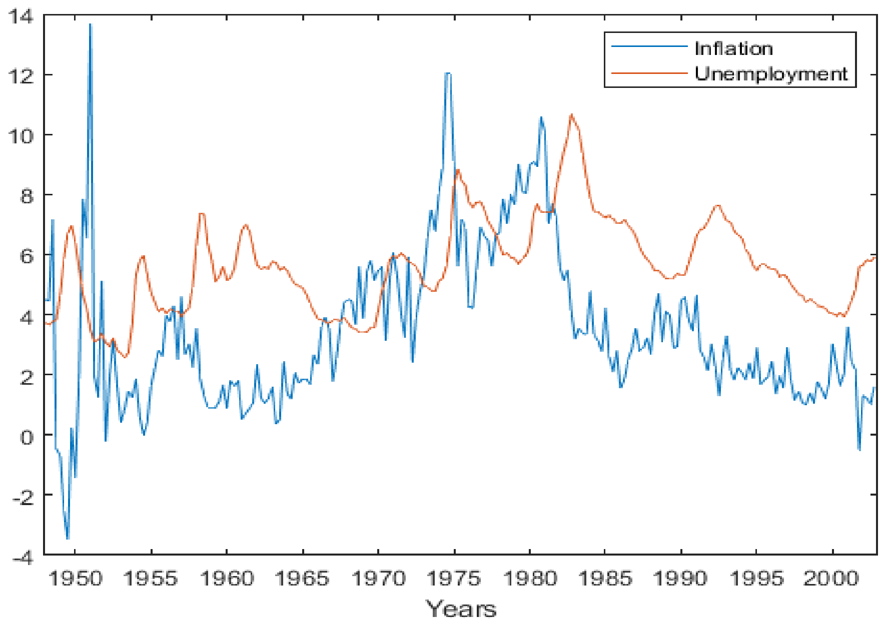
The sample has been divided into two periods: Pre-Volcker (1960:Q1-1979:Q2) and Post-Volcker (1979:Q3-2002:Q4), to capture the difference in outcomes across two eras of central banking. Two strands of narratives of the Great Inflation, viz, 'bad policy' and 'commitment' attribute the observed difference in the two eras to systematic passive response of policy to inflationary pressure in the economy and high, unrealistic target rate of unemployment by the monetary authority respectively. Section 1.1 elucidates on various narratives of the Great Inflation.

In Table 1, we see that average inflation is one percentage point lesser in the post-Volcker era. Additionally, variance of inflation is remarkably lesser in this era. However, average unemployment is 0.5% higher in post-Volcker era while volatility of unemployment is approximately same. This episode is also interesting for its duration and

[1] Throughout the paper, inflation is calculated as annualised quarterly growth rate of gdp deflator and unemployment is calculated as quarterly average of monthly civilian unemployment rate.

asymmetry- while, high and persistent upward trend in inflation lasted around 15 years, disinflation took around 5 years. Inflation increased from 0.9% in 1960:Q1 to 12.01% in 1978:Q4, before falling to 2% by 1985:Q4. Popularly known as 'Volcker disinflation', inflation reduced from 10% in 1980:Q4 to 3.1% in 1983:Q1. Finally, an important fact about this period is the breakdown of Phillips curve relationship in 1970's; there was positive correlation between inflation and unemployment with unemployment lagging behind inflation. The mentioned facts are quite easily visible in Figure 1.

Figure 1: US quarterly Inflation and Unemployment Data



We explain the Great Inflation as the rational and endogenous outcome of the learning process of policymakers about the true model of the economy. Deviating from rational expectations, policymaker in this model has imperfect information about the behavior of the economy. Every time period, he updates his beliefs about the economy by using constant gain (CG) learning rule. The learning rule describes how policymaker updates his estimate/belief about unknown parameters in the model. Assuming the estimated parameters to be perfect, he formulates optimal policy, conditional on his beliefs, by minimizing an infinite horizon, quadratic loss function.

We find that rational policymaking behavior in this framework results in disequilibrium dynamics characterized by high and persistent inflation when initial beliefs are incorrect. Particularly, the results show that policymakers underestimated natural rate of unemployment, persistence in inflation in 1960s. Policy reaction, conditional on beliefs, was hence more expansionary than optimal. The resulting inflation was not fought immediately since persistence was underestimated. Hence, any inflationary pressure was expected to fade away quickly. Finally, evolving beliefs about the sacrifice ratio or slope of Phillips Curve delayed anti-inflationary policy in the 1970's, as policymakers found the sacrifice ratio to be unfavorable. We further show that the target rate of unemployment of the policymaker changed substantially in the second part of the sample (1979:Q3- 2002:Q4) supporting the argument of time inconsistency proposed by Kydland and Prescott (1977), Barro and Gordon (1983). It also explains the more aggressive response of policymakers to inflationary pressure since Volcker. We believe that most of the narratives about Great Inflation have some truth to them, while they are not exhaustive in their ability to explain the episode fully. It is the combined effect of various factors that caused the Great Inflation.

Narratives

In this section, various strands of narratives about the Great Inflation are reviewed. The traditional explanation hinges on time inconsistency [Kydland and Prescott (1977)] that arises in the context of discretionary policymakers with rational expectations, playing a static (or) dynamic game with private agents. Pursuit of high target rate of unemployment and/or higher weight on unemployment stabilization relative to inflation stabilization in addition to the extent of nominal price rigidity produces an inflationary bias in the optimal response of policymakers to the prevailing state of the economy. An extension of this explanation relies on expectations traps that arise in these scenarios. Policymakers might pursue inflationary policies to meet private sector's expectations in order to avoid recessions (Chari, Christiano, and Eichenbaum 1998). Barro and Gordon (1983) also pursue this narrative. However, Ireland (1999) empirically verifies the time inconsistency story and finds limited empirical validation for this narrative, though he does not reject the presence of time inconsistency.

Another strand of narrative is based on supply shocks or bad luck. This strand holds the OPEC oil price shocks to be the primary drivers of high inflation in 1970s. Cogley and Sargent (2001), Sims and Zha (2004) find that non-policy shocks, particularly supply shocks were higher in the 1960s and 1970s than in the last two decades of 20^{th} century. The issue with this narrative is that the shocks are not enough to generate persistent inflation for almost two decades without sufficient support from policy.

Another major line of research blames bad policy and poor idea about the model governing the economy. Particularly, Clarida, Gali and Gertler (2000) and Lubik and Schorfheide (2004) find that policy response has been more responsive to inflationary pressure since the chairmanship of Paul Volcker. However, other studies have contested this finding [Primiceri (2005a), Sims and Zha (2004)].

The learning explanation of the Great Inflation is based on the fact that, in real time, policymakers have imperfect information about important features of the economy Orphanides(2000, 2002). Orphanides and Williams (2006) examine the Great Inflation as a period characterised by improper understanding of the natural rate of unemployment. Even when the policymakers accept the natural rate hypothesis, underestimation (overestimation) of the natural rate of unemployment would provide incentive to a central bank to pursue expansionary (contractionary) monetary policy. This line of explanation has also been proposed by Cukierman and Lippi (2005) and Reis (2003). Cogley and Sargent (2004) also interpret the Great Inflation as the result of learning on the part of policymakers. In this paper, We ascribe to the learning explanation of the Great Inflation and further examine evidence of other narratives within this framework.

THE LEARNING MODEL

"It ain't what you don't know that gets you into trouble. It is what you know for sure that just ain't so"

-Mark Twain

This section presents a backward looking 'New Keynesian' model as the true model of the economy. The model presented in this paper is closest to Primiceri (2007).

$$\begin{aligned} \pi_t &= \pi_t^e - \theta(L)(u_{t-1} - u_{t-1}^N) + \epsilon_t && (1a) \\ (u_t - u_t^N) &= \rho(L)(u_{t-1} - u_{t-1}^N) + V_{t-1} + \eta_t && (1b) \\ u_t^N &= (1-\gamma)u^* + \gamma u_{t-1}^N + \tau_t && (1c) \\ \pi_t^e &= \big(1 - \alpha(1)\big)E_{t-1}\pi_t + \alpha(1)\pi_{t-1} && (1d) \end{aligned}$$

Equation (1a) is a standard, expectations augmented Philips Curve, where inflation is affected by lagged deviation of unemployment from the natural rate. ϵ_t is an i.i.d. $N(0, \sigma_\epsilon^2)$, Aggregate Supply (AS) shock. $\theta(L)$ is the slope of the Phillips Curve. Equation (1b) is an Aggregate Demand (AD) equation, where deviation of unemployment from the natural rate is dependent on its persistence- $\rho(L)$, the policymaker's choice variable- V_t and a random demand shock- η_t with standard properties, i.i.d. $N(0, \sigma_\eta^2)$. Within the context of monetary economics, real interest rate is considered as the policy variable (V_t). Here, the policy variable is interpreted as capturing the combined effect of monetary and fiscal policy. Equation (1c) specifies the path of the natural rate of unemployment. u^* is the unconditional mean while $\gamma = 0.99$, in the estimation procedure. The natural rate is hence modelled, as a highly persistent AR(1) process. Equation (1d) describes how expectations are formed in the economy. A proportion of private agents are assumed to have rational expectations, while, the remaining have adaptive expectations. Substituting, equation (1d) into (1a),

$$\pi_t = \alpha(L)\pi_{t-1} - \theta(L)(u_{t-1} - u_{t-1}^n) + \epsilon_t \tag{2}$$

In Equation (2), $\alpha(L)$ is the proportion of agents who have adaptive expectations. Equations (1b), (1c) and (2) together specify the closed, true model of the economy. Note that in this model, policy reaction at time '*t*' affects unemployment at '*t+1*', which in turn affects inflation at '*t+2*'.

Policymaker Behavior

This subsection explains the behavior of policymaker every time period. Policymaker is assumed to maximize an anticipated utility function to formulate the optimal policy every time period. Concretely, they are assumed to minimize a quadratic loss function (equation 3) with weights on inflation and unemployment stabilisation subject to the constraints in (4a) and (4b).[2] The constraints are essentially the estimated AS and AD curve at time t, which define the perceived law of motion (PLM).[3] Policymakers are also assumed to care about policy smoothing, i.e., large changes to the policy variable adds to their loss. Formally, they minimize,

$$minL_t(\{V\}_{s=t}^{\infty}) = \hat{E}_t \Sigma_{s=t}^{\infty} \delta^{s-t}[(\pi_s - \pi^*)^2 + \lambda(u_s - k\hat{u}_{s|t}^N)^2 + \phi(V_s - V_{s-1})^2], \tag{3}$$

subject to the following constraints:

$$\begin{aligned} \pi_s &= \hat{c}_{\pi,t} + \hat{\alpha}_t(L)\pi_{s-1} - \hat{\theta}_t(L)\left(u_{s-1} - \hat{u}_{s-1|t}^N\right) + \hat{\epsilon}_s, \qquad s \geq t+1 \\ (u_s - \hat{u}_{s|t}^N) &= \hat{c}_{u,t} + \hat{\rho}_t(L)\left(u_{s-1} - \hat{u}_{s-1|t}^N\right) + V_{s-1|t} + \hat{\eta}_s, \qquad s \geq t+1. \end{aligned}$$

[2] Throughout the paper, belief of the policymaker about an unobservable is denoted by circumflex.

[3] PLM is the policymaker's idea/estimate, at any time period, about the relationship between the variables that underlie the economy. The next sub-section discusses Percieved Law of Motion (PLM) and Actual Law of Motion (ALM).

In equation (3), $L(.)$ is a quadratic objective function, which captures the disutility/loss to policymakers from a particular realisation of inflation, unemployment and the policy variable. The term in the bracket on LHS implies that the loss function is minimized with respect to V. Policymakers minimise the discounted expected loss arising from deviation of inflation and unemployment from their respective targets. 'λ' captures the weight on unemployment stabilisation, while 'ku_t^N' determines the target rate of unemployment, as in Barro and Gordon (1983). Note that, a value of 'k' close to zero is evidence of time inconsistency narrative. However, if 'k' is close to one, then the target rate of unemployment is the natural rate and hence the inflationary bias arising under time inconsistency is avoided. 'ϕ' is the 'smoothing parameter', which captures the behavior of policymakers to avoid large changes in policy. The parameters $\delta, \lambda, \pi^*, k$ and ϕ are known to the policymakers. In the constraints [equation (4a) and (4b)], $\hat{c}_{\pi,t}$ represents beliefs of policymaker about the average inflation, while $-\hat{c}_{u,t}$ denotes the level of policy that does not affect unemployment.

Policymakers minimize the loss function, subject to the constraints with respect to the policy variable, V_t. The minimisation procedure endows the policymaker with an optical plan, $\{V_{s|t}\}_{s=t}^{\infty}$. However, he/she implements only $V_{t|t} = V_t$ - the optimal policy for time t conditional on the information set available at time t.

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

where $\hat{\beta}_t$ represents the policymaker's estimate of model parameters at time t, which he assumes to be the true value of the parameters. S_t denotes the set of relevant state variables and beliefs about unobservable states of the economy, while $g(\hat{\beta}_t)$ is the solution to the linear-quadratic problem, obtained by solving the corresponding Riccati equation.

Learning

This subsection elucidates the constant gain algorithm which defines how policymakers in our model learn and update existing beliefs. We assume that while policymakers are aware of the functional form of the model, it is the unobservables[4] that they have imperfect knowledge about. More specifically, policymakers continually update their knowledge of the natural rate of unemployment (u_t^n), persistence of inflation ($\alpha(L)$) and slope of Phillips Curve ($\theta(L)$). The model considered in the previous section governs the Actual Law of Motion (ALM), while policymakers estimate of the unobservables characterises their real time understanding of the relationship between the variables in the model, aka, the perceived law of motion (PLM). Equilibrium steady state is defined as the convergence of PLM to ALM. Since the difference between the two lies in the estimate of unobservables, convergence of these estimates to their true, rational expectations equilibrium values guarantees convergence of PLM to ALM.

We assume that policymakers act as econometricians in forming their beliefs. They follow a variant of recursive least squares, called constant gain (CG) learning rule. A CG learning rule essentially places equal weightage on all data points, while a traditional least square places diminishing weights on new data. The use of CG rule is to incorporate the idea that policymakers are aware and suspicious of drifts and breaks in the relationship between variables. Every time period, policymakers update their estimate of the unobservables the following way:

$$\hat{u}_{t|t}^N = \hat{u}_{t-1|t-1}^N + g_N R_{N,t-1}^{-1}\left(u_t - \hat{u}_{t-1|t-1}^N\right) \tag{5a}$$

$$R_{N,t} = R_{N,t-1} + g_N\left(1 - R_{N,t-1}\right) \tag{5b}$$

In equation (5a), the estimate of natural rate at time t is recursively updated based on the deviation of unemployment at time t from the natural rate at time $(t-1)$. We assume that unemployment is equal to the natural rate on average and hence larger deviations of unemployment from the current estimate of natural rate suggest a drift in the natural rate. The weight given to deviation depends on the gain

[4] In rest of the paper, the term 'unobservables' constitutes the following variables: natural rate of unemployment, persistence of inflation and slope of Phillips curve.

parameter (g_N) and the inverse of the variance of the regressor (R_N)- the constant one here. Given the estimate of natural rate, policymakers update their estimate of the model parameters recursively:

$$\hat{\beta}_t^i \quad = \hat{\beta}_{t-1}^i + gR_{i,t-1}^{-1}x_t^i\left(y_t^i - x_t^{i\;\hat{\beta}_{t-1}^i}\right), \tag{6a}$$

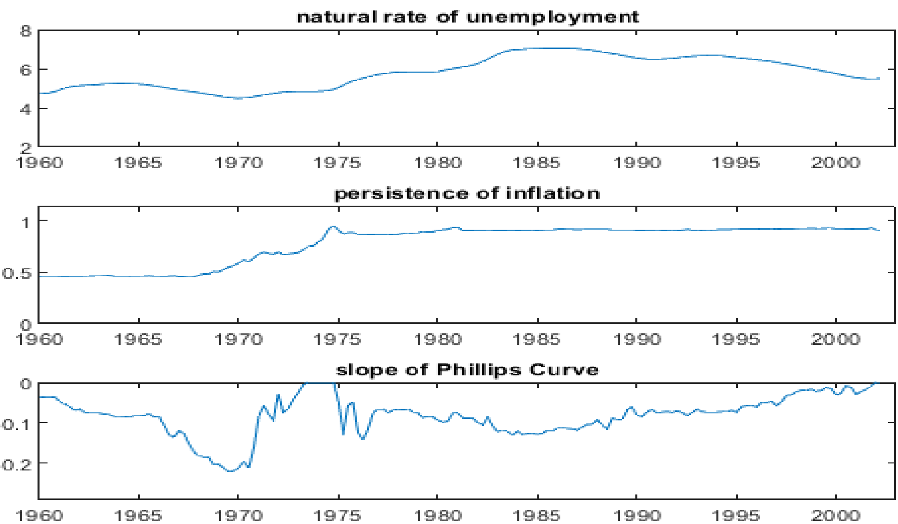
$$R_{i,t} \quad = R_{i,t-1} + g\left(x_t^i x_t^{i\,\prime} - R_{i,t-1}\right), \qquad i = (\pi, u), \tag{6b}$$

where

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

The above equations (6a and 6b) describe the learning rule corresponding to the model parameters. Note that the gain parameter is different for natural rate (g_N) and the model parameters (g). Given the estimate of the parameters, coupled with the estimate of natural rate from equations (5a and 5b), the policymaker has the information necessary to formulate optimal policy every time period.

Figure 2: Perceived Value of the Unobservables- $\hat{u}_t^N, \hat{\alpha}_t(L), \hat{\theta}_t(L)$ Respectively



ESTIMATION METHODOLOGY

In this section, we present the estimation methodology of the adaptive learning methodology described in the previous section and that of the model parameters. Quarterly data from 1948-1960 is used to estimate initial beliefs using Discounted Least Squares.[5] In the loss function, $\delta = 0.99, \pi^* = 2$ and $\lambda = 1$. As mentioned above, $\gamma = 0.99$ and further $\sigma_\tau^2 = 0.0199$. In the learning process, the gain $g_N = 0.03$ and $g = 0.015$. The difference in the gain parameters is meant to impose the prior belief that policymakers are more watchful of drift in natural rate relative to model coefficients. The initial beliefs are as follows:

$\left[\hat{c}_\pi, \hat{\alpha}_1, \hat{\alpha}_2, \hat{\theta}_1, \hat{\theta}_2, \hat{c}_u, \hat{\rho}_1, \hat{\rho}_2, \hat{u}^N\right] =$
$[1.156, 0.33, 0.131, -0.914, 0.885, 0.012, 1.536, -0.717, 4.701]$.

We start the simulation in 1960:Q1. Every quarter, policymakers update their estimate of the unobservables. Conditional on these estimates, they choose the policy reaction by minimizing the loss function. Next time period, they update their beliefs based on the one period ahead forecast error. Policymakers treat their estimates/beliefs every period to be free of error. Figure 2 presents the CG real time estimate of the unobservables.

We use state space framework to estimate the model parameters, which are interpreted as the 'true' parameter values. The state space estimates serve as the benchmark against which underestimation or overestimation of parameters is established. The state space model uses Maximum likelihood method to estimate the parameters and the state variables.

The methodology adopted to obtain time varying estimates is as follows - the model is divided into two samples; point estimates of the

[5] Discount rate is set $\Delta = 1 - 1/120$.

parameters, including persistence of inflation ($\alpha(L)$) and slope of Phillips Curve ($\theta(L)$) are obtained alongside smoothed estimates of the natural rate of unemployment. The smoothed estimate of the natural rate is then used as an exogenous predictor in the below framework (equations 7a to 7e) and the parameters of the model are estimated again allowing 'θ' and 'α' to vary over time.

$$\begin{aligned}
\pi_t &= \alpha_{1t}\pi_{t-1} + \theta_{1t}(u_{t-1} - u_{t-1}^n) + \theta_{2t}(u_{t-2} - u_{t-2}^n) + \epsilon_t \\
(u_t - u_t^N) &= \rho_1(u_{t-1} - u_{t-1}^N) + \rho_2(u_{t-2} - u_{t-2}^N) + V_{t-1} + \eta_t \\
\alpha_{1t} &= \alpha_{1t-1} + v_t \\
\theta_{1t} &= \theta_{1t-1} + w_t \\
\theta_{2t} &= \theta_{2t-1} + w_t
\end{aligned}$$

This seemingly repetitive iteration mechanism is due to the fact that the kalman filter is a linear filtering system. A single estimation step where natural rate and slope of PC are estimated simultaneously is not possible since the two interact multiplicatively in equation (7a), making the system non-linear. We fix the variance of shocks to persistence of inflation (σ_v^2) to 0.001 in order to fully identify the model. θ_1 and θ_2 are the lagged impact of the same variable (unemployment) on inflation. Hence, they are assumed to come from the same distribution with variance 'w'.

Figure 3: α_t- Comparison of MLE and CG Estimate

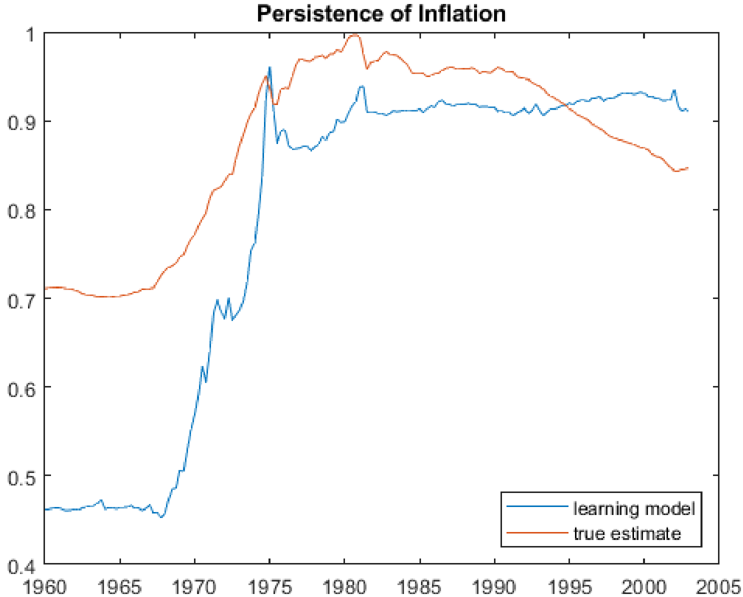


Table (2) presents the point estimates, while Figure(3), Figure(4) and Figure (5) respectively plot the smoothed estimate of the persistence in inflation (α), natural rate of unemployment (u_t^N) and persistence of inflation, alongside their respective estimates obtained via the learning model. The obtained estimate of 'true' natural rate is close to estimates in other studies such as Staiger, Stock and Watson (2001) and Krump, Eusepi, Giannoni and Sahin (2019).

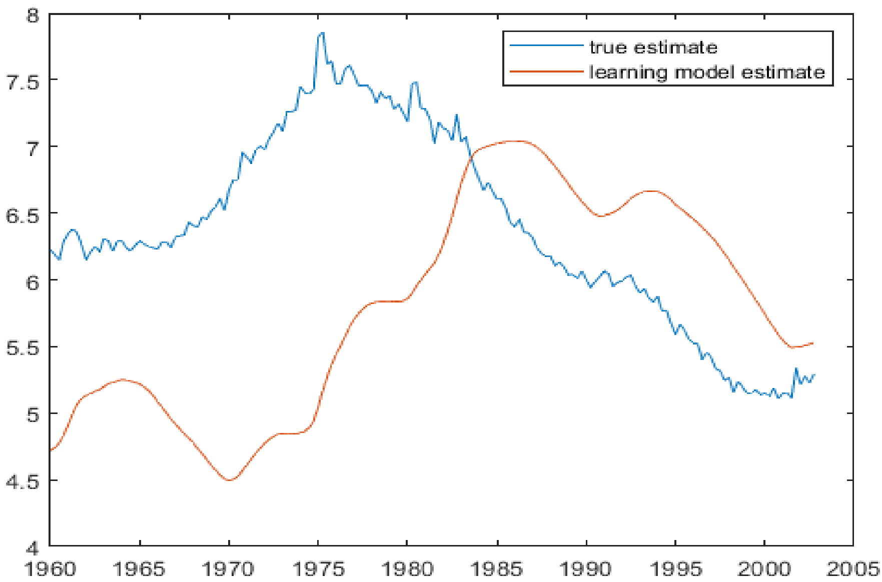
RESULTS

This section discusses the results of the estimation methodology. We also present evidence from Economic Report Of President (EROP) to support my narrative.

1960s

It has been widely established that policymakers had highly optimistic beliefs about the potential output and natural rate of unemployment (Orphanides(2002)). It has also been established in literature that policymakers of this period underestimated persistence of inflation and they believed in the existence of long run inflation-output trade off. Romer and Romer (2002)(Romer and Romer 2002) go to the extent of questioning if policymakers in 1960's were aware of the existence of a natural rate to begin with. Similarly, Orphanides (2002) finds that a real time estimate of the potential output during 1960s was significantly higher than revised ex-post data of the same.[6]

$Figure\ 4: u_t^N$ - Comparison of MLE and CG Estimate



From Figure 3, it can be seen that real time estimate of the persistence in inflation ($\alpha(L)$) was highly optimistic in 1960s. Real time

[6] Further evidence of the same can be found in DeLong (1997)(Long 1995), Mayer (1999).

estimates of $\alpha(L)$ (blue line) were below 0.5 until the end of 1960s, when policymakers started revising their estimate upward. Hence, any increase in inflation was not expected to persist for a long time. However, in the same decade, the true value of $\alpha(L)$ (red line) was not less than 0.7. Further, in line with the narrative put forward in this study, Figure (4) tells that real time estimate of the natural rate of unemployment ($\hat{u}_t^n$) was significantly lower than its true estimate. While the former was mostly below 5% and reached a trough of 4.5% in the end of 1960s, the latter was just above 6% at the start of the decade and moved up to 7.5% by the end of the decade. As per our estimates, the difference between the two widened to around 3% by the end of the decade.

It has also been established that policy objective during this period was full employment [Meltzer, 2010). Hence, a low estimate of the natural rate combined with the belief of low persistence in inflation underpinned the attitude of policymakers in 1960s. As a result policy was over expansionary or in other words, accommodative of inflation as it was believed that there was scope to reduce unemployment without generating inflation.

1970s

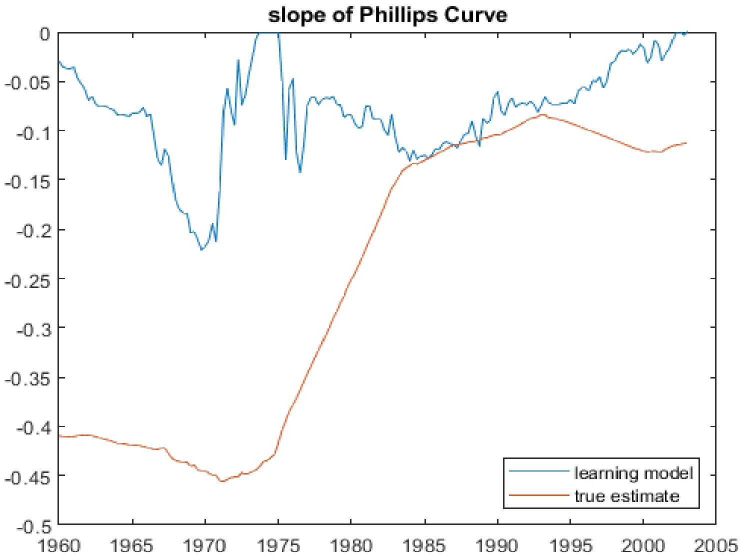
In 1970s, policymaker's estimate of persistence improved significantly (Figure 3). Belief about persistence converged to its true value by mid 1970s and largely remained around the true value for the rest of the sample. However, anti-inflationary policy was not enacted since belief about inflation-output trade off worsened (Figure 5). Additionally, belief about natural rate was still lower than the true value (Figure 4). Policymakers tried to push unemployment above the perceived natural rate but inflation did not come down. As a result, estimate of the slope of Phillips Curve was revised towards zero. In the Figure 5, we see steep revision of belief about θ towards zero in 1970s. A flatter Phillips curve implies a costlier disinflationary process. From Figure 5, it is also visible that perceived inflation-output trade off was pessimistic in this decade. Policymaker's estimate of trade off and hence the cost of disinflation was higher than the reality.[7] We find evidence of this in the narrative. The EROP 1972 comments, "tendency to an unsatisfactorily high rate of inflation which persists over a long period of time and is impervious to variations in the natural rate of unemployment, so that the tendency cannot be eradicated by any feasible acceptance of unemployment". Hence, the 1970s was characterized by accurate beliefs about persistence, improved but not accurate belief about natural rate and pessimistic belief about the cost of disinflation. As a result, rational action, conditional on beliefs was not anti-inflationary policy but inaction to inflationary pressure due to the high perceived cost of disinflation. This explains why inflation continued to rise through 1970s.

1980s

There has been disagreement in literature about what changed between 1970s and 1980s. Within the context of our framework, we see that real time estimates of the tradeoff (θ) started improving from the start of 1980s. By mid 1980s, the learning process ensured that beliefs about slope of Phillips Curve, alongside the persistence parameter and the natural rate converged around their respective true values. Convergence ensured that the errors in forecasts of inflation and unemployment reduced. Further, we see from Table 2 that the value of k, which determines the rate of unemployment targeted by policymakers increased drastically in the second part of the sample. Policymakers target rate of unemployment is close to zero in the first part of the sample, while it increases significantly to the natural rate in the second part of the sample. This lends evidence to the time inconsistency narrative within our adaptive learning framework and points to one of the major changes in policymaking that has helped reign in low, stable inflation since 1980s;

[7] In Figure 5, the blue line plots the evolution of policymaker's belief about the slope of Phillips Curve while the red plots the evolution of the true value of the same.

Figure 5: θ_t- **Comparison of MLE and CG Estimate**



policymakers understood the inflationary bias that arises when they target an artificially low rate of unemployment[8]. This adjustment in the targeted rate of unemployment made optimal policy to be more aggressive towards inflation. Hence, convergence of beliefs to their respective true values coupled with a change in the outlook of policymakers reflected by the pursued target rate of unemployment ensured that perceived optimal policy was indeed optimal, thus bringing down and maintaining low inflation.

DISINFLATION

The prolonged nature of the disinflation process was due to the fact that by 1980s, the true value of the tradeoff (θ) faced by policymakers was higher than what they faced in 1960s. Hence, in comparison to 1960's,

[8] The appendix derives a theoretical model that shows how inflation outcomes are affected by the target rate of unemployment.

higher rate of increase in unemployment over the natural rate was necessary in 1980s for a percentage point reduction in inflation.

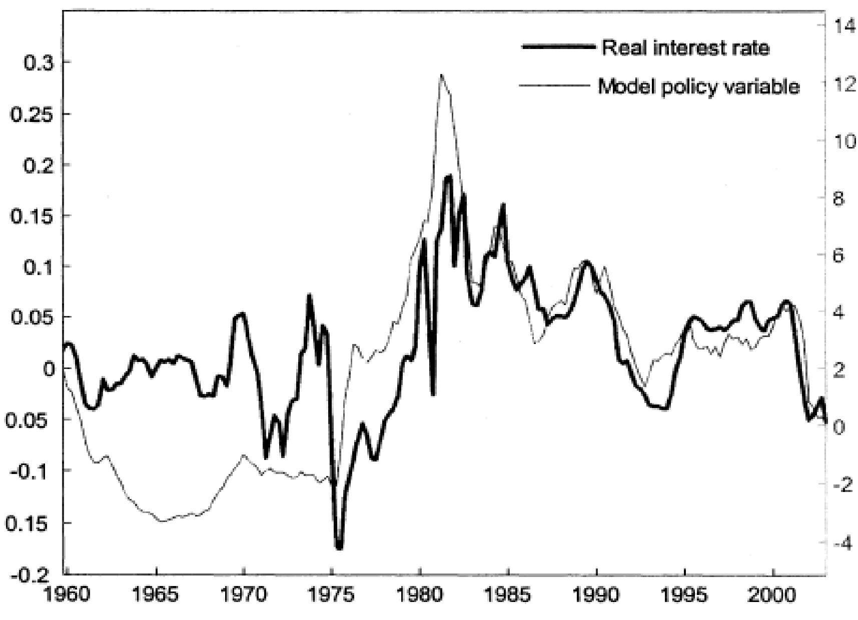
Table 2: Maximum Likelihood Estimate

Coefficients	1960:Q1-1979:Q2	1979:Q3-2002:Q4
ρ_1	1.644 (0.097)	1.714 (0.086)
ρ_2	-0.706 (0.101)	-0.779 (0.082)
σ_ϵ^2	1.391 (0.231)	0.779 (0.12)
σ_η^2	0.0519 (0.012)	0.03 (0.007)
σ_w^2	0.005 (1.49)	0.003 (1.18)
ϕ	6184 (1595)	1182 (2557)
k	0.0419 (0.091)	0.995 (0.019)

We average the smoothed state estimate of θ from 1960:1 to 1969:4 and from 1980:1 to 1989:4 to compare the cost of disinflation- for a given natural rate, a percentage point reduction in inflation required 3% increase in unemployment above the natural rate while 6.8% increase in unemployment rate above the natural rate was required in 1980s to reduce inflation by 1%. While, this measure is only an approximation, the magnitude of the difference throws light on the change in trade off faced by policymakers in 1980s in comparison to 1960s. Additionally, persistence remained high till late 1980s thus making it necessary to keep unemployment above the natural rate for a prolonged period of time to reduce inflation, thus making the disinflationary episode a costly one. We average the deviation of unemployment from the estimated natural rate during 1980:1 to 1986:4 as a measure of the total cost of disinflation. On average, unemployment was 4% above the natural rate per year.

In Table 2, variance of AS shocks (σ_ϵ^2) is twice as large in the first part of the sample. This lends considerable support to the 'supply shocks' interpretation of this episode. Figure 6 plots the model generated policy response variable (V_t) against real effective interest rate, which has largely been the variable that represents monetary policy response in literature and is known to have been used by policymakers in the sample period as response to economic fluctuations. Our estimates closely match the real interest rate, particularly in the second part of the sample. The discrepancy in first part of the sample is expected since we interpret the model policy variable as the combined effect of fiscal and monetary interventions.

Figure 6: Model Policy Variable- V



SUMMARY AND FURTHER IMPROVEMENTS

This study extends Primiceri (2007) by presenting evidence on the presence of time inconsistency in the actions of policymakers in the first part of the sample (1960:Q1- 1979:Q2) and by providing time varying estimates of slope of Phillips curve and persistence of inflation as additional quantitative evidence of the narrative. The quote by Mark Twain mentioned in the beginning of section 2 is meant as a warning in being sure of beliefs which are ultimately incorrect. In line with the quote, the central idea of the study is the role of incorrect beliefs in explaining the Great Inflation.

In summary, We find that a consistent explanation of the Great Inflation is given by a learning framework where rational policy in the presence of continual learning about the unobservables on the part of the policymaker, brings about disequilibrium dynamics characterised by rising and persistent inflation. Further, the results obtained advocate the idea that most existing narratives have some truth to them while they are incapable of explaining all the stylized facts of this episode. The learning framework provides a baseline specification that gives scope to throw light on other narratives such as 'time inconsistency' and 'supply shock'.

One of the limitations of this study is the iterative mechanism used to obtain time varying estimate of persistence in inflation and slope of the Phillips curve. Further attempts could be made to compute the estimates in a more efficient manner. One possible way is to use official estimates of output gap in place of unemployment gap. Another way would be to opt for a non-linear filtering system where state variables could be in non-linear form. This study can also be extended to understand the determinants of the natural rate of unemployment as generated by the model, to get a clearer picture of what changed in the real economy between 1960-1990.

APPENDIX

In this section, a simpler version of the model considered in this study is solved to theoretically establish the role of 'k' in determining the optimal policy every period and hence future path of inflation and unemployment. Assume that policymakers choose the optimal value of the policy variable (V_t) every time period, by minimizing the following loss function:

$$minL_t(V_t) = E_t[(\pi_{t+2} - \pi^*)^2 + \lambda(u_{t+1} - ku_{t+1}^N)^2, \tag{8}$$

subject to the following constraints:

$$\begin{aligned} \pi_t &= \alpha\pi_{t-1} - \theta(u_{t-1} - u_{t-1}^N) + \epsilon_t, && (9a) \\ (u_t - u_t^N) &= \rho(u_{t-1} - u_{t-1}^N) + V_{t-1} + \eta_t, && (9b) \end{aligned}$$

Where, the variables are defined as in the rest of the paper. In equation (8), loss this period depends on the expected deviation of unemployment from the natural rate one period ahead while deviation of inflation from its target two periods ahead affects loss this period. The loss function has been defined this way to throw light on the relative impact of inflation and unemployment on the optimal policy reaction, since policy at time 't' affects unemployment at time '$t+1$' and inflation at time '$t+2$' in the New Keynesian model described in section (2). Further, this simplified loss function does not contain discount rate and a policy smoothing term since the results of the analysis explored here is indifferent to these additional complexities. We proceed to solve the model to obtain the optimal policy reaction. Equation (9b) becomes:

$$\begin{aligned} u_t &= u_t^N + \rho(u_{t-1} - u_{t-1}^N) + V_{t-1} + \eta_t && (10a) \\ \Rightarrow (u_{t+1} - ku_{t+1}^N) &= (1-k)u_{t+1}^N + \rho(u_t - u_t^N) + V_t + \eta_{t+1} && (10b) \end{aligned}$$

Equation (9a) becomes:

$$\begin{aligned} \pi_{t+2} - \pi^* &= \alpha\pi_{t+1} - \theta(u_{t+1} - u_{t+1}^N) - \pi^* + \epsilon_{t+2} && (11a) \\ \Rightarrow \pi_{t+2} - \pi^* &= \alpha\pi_{t+1} - \theta[\rho(u_t - u_t^N) + V_t] - \pi^* + \epsilon_{t+2} && (11b) \end{aligned}$$

Substituting equations (10b) and (11b) in (8)[9],

$$L_t = E_t[(\alpha\pi_{t+1} - \theta\rho(u_t - u_t^N) - \theta V_t - \pi^*)^2 + \lambda[(1-k)u_{t+1}^N + \rho(u_t - u_t^N) + V_t]^2], \qquad (12)$$

Minimizing (12) wrt V_t,

$$0 = \frac{dL_t}{dV_t} = E_t[2\lambda[(1-k)u_{t+1}^N + \rho(u_t - u_t^N) + V_t] - 2\theta(\alpha\pi_{t+1} - \theta\rho(u_t - u_t^N) - \theta V_t - \pi^*)] \qquad (13a)$$

$$0 = E_t[u_{t+1}^N[2\lambda(1-k)] + (u_t - u_t^N)[2\lambda\rho + 2\theta^2\rho] + V_t(2\lambda + 2\theta^2) - 2\theta\alpha\pi_{t+1}] + 2\theta\pi^* \qquad (13b)$$

Rearranging the terms,

$$\boxed{V_t = \frac{\theta}{\lambda + \theta^2}(\alpha E_t\pi_{t+1} - \pi^*) - \rho(u_t - u_t^N) - \frac{\lambda(1-k)}{\lambda + \theta^2}E_t u_{t+1}^N} \qquad (14)$$

Equation (14) is the best response function of the policymaker. The last term in RHS tends to zero as $k \to 1$. Intuitively, as 'k' tends towards zero, the target rate of unemployment (ku_t^N) also tends to zero. For a given unemployment rate and natural rate, a fall in the target rate of unemployment (ku_t^N) generates expansionary policy and inflation subsequently. From equation (14),

$$\frac{\partial V_t}{\partial k} = \left(\frac{\lambda}{\lambda + \theta^2}\right) u_{t+1}^N \qquad (15)$$

Note that k lies between 0 and 1. As k falls, policy becomes more expansionary (V_t falls) and accomodative of inflation. Hence, the sign of the partial effect of 'k' on 'V_t' is positive in equation (15). Policy every period follows the rule specified in equation (14). When $k = 1$, the last term on RHS disappears which implies that the average level of policy is lower whenever $0 \leq k < 1$ in comparison to when $k = 1$. To see this, let the economy be in equilibrium at time t. In equilibrium, current and expected future values of unemployment are equal to the natural rate. The equilibrium conditions translate to:

[9] In equation (12), there are no error terms since the prior belief that $E_t\epsilon_{t+i} = E_t\eta_{t+i} = 0 \forall i \in Z^+$.

$$u_t = u_t^N,$$
$$E_t u_{t+1} = E_t u_{t+1}^N$$

Equilibrium in real economy implies that $E_t \pi_{t+2} = \alpha E_t \pi_{t+1}$. Then, the best response of policymaker in equilibrium becomes:

$$\boxed{V_t^e = \frac{\theta}{\lambda + \theta^2}(\alpha E_t \pi_{t+2} - \pi^*) - \frac{\lambda(1-k)}{\lambda + \theta^2} E_t u_{t+1}^N}, \tag{16}$$

where 'V_t^e' is the policy reaction in equilibrium. Note that, in equilibrium, if '$k = 1$', optimal policy response is higher, implying tighter monetary policy. If '$k < 1$', optimal policy in equilibrium gets relatively more accomodative of inflation as '$k \to 0$'. This increases the mean inflation - optimal policy response in equilibrium has an inflation bias. In the long run, inflation equals expectations and hence unemployment equals its natural rate. However, the long run inflation is higher as 'k' tends to zero.[10]

[10] The inflation bias generated by 'k' in various model specifications can be seen in Barro & Gordon (1983), Gordon (1981) and Kydland and Prescott (1987).

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