CAN UNIVARIATE TIME SERIES MODELS OF INFLATION HELP DISCRIMINATE BETWEEN ALTERNATIVE SOURCES OF INFLATION PERSISTENCE?

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Can Univariate Time Series Models of Inflation Help Discriminate Between Alternative Sources of Inflation Persistence

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Abstract

When it comes to measuring inflation persistence, a common practice in empirical research is to estimate univariate autoregressive moving average (ARMA) time series models and measure persistence as the sum of the estimated AR coefficients. We examine four potential sources of lag dynamics in inflation: the evolution of policymakers' willingness to stabilize output, shifts in the mean inflation rate, imperfect credibility and learning and unemployment persistence. We show that the reduced-form solution for inflation in all these models have an ARMA(p,q) representation. By implication estimating a reduced-form for inflation will not be able to distinguish among these alternative hypotheses. We illustrate this using US and UK data.

ACKNOWLEDGMENT

INTRODUCTION

Empirical studies on monetary policy have pointed out significant shifts in the policy over the past decades.[1] Parallel to these shifts in the conduct of policy, the dynamics of inflation has changed over time as well: the persistence of inflation has dropped substantially in the US and UK since the early 1980s.[2] This has spawned a large body of empirical work examining the joint facts of inflation persistence and regime change.[3]

When it comes to measuring inflation persistence, a common practice in empirical research is to estimate univariate autoregressive moving average (ARMA) time series models and measure persistence as the sum of the estimated AR coefficients.[4] However, there is little consensus on why persistence has changed over time. For example, Beechey and Österholm (2007) attribute the rise and fall of US inflation persistence to the evolution of policymakers' willingness to stabilize output. In their model the degree of inflation persistence is determined by the central bank's relative preference for output stability. As the preference for output stability rises (or falls), so too does the persistence of inflation.

An alternative explanation focuses on the possibility of a structural break in the inflation process (Cogley and Sargent (2001) and

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[1] Clarida *et. al.* (2000) document changes in the post-war US monetary policy reaction function. See Meenagh *et. al.* (2009) for a detailed overview of the UK policy environment in the post-war period.

[2] We define persistence as the speed with which inflation converges to equilibrium after a shock in the disturbance term.

[3] The analysis in Barsky (1987), Evans and Wachtel (1993), Brainard and Perry (2000), Taylor (2000), Cogley and Sargent (2001) and Levin and Piger (2002) suggest that shifts in the persistence of US inflation correspond reasonably well to shifts in monetary policy regime. For the UK a variety of studies have created a consensus that persistence has varied with changes in monetary regime (Benati (2004) and Meenagh *et. al.* (2009)).

[4] For example, Clark (2006) finds that the sum of the autoregressive (AR) coefficients for the aggregate inflation series is about 0.9 for the US. Batini (2006) finds that for the Euro-zone 1970-2002 the coefficients sum to around 0.7, varying across countries.

Levin and Piger (2002)). For example, shifts in the central banks inflation target can induce permanent shifts in the mean inflation rate. Failure to account for such breaks could yield spuriously high estimates of the degree of persistence. Thus, according to this view inflation persistence was high in the 1970s because of substantially higher inflation goals. In contrast, lower persistence observed during the remainder of the post-war period reflects lower inflation goals (see Kozicki and Tinsley (2003) and Ireland (2007)).

Another approach to explain lag dynamics in inflation relies on imperfect credibility and learning (see Erceg and Levin (2003) and Westelius (2005)). The idea is that if policy suffers from imperfect transparency and credibility, then the public is forced to learn the true intentions of the monetary authorities by observing real outcomes. It is this learning process that affects inflation dynamics. These models predict that a monetary regime that lacks credibility, learning by private agents can generate a significant amount of inflation persistence. In contrast, in a stable and transparent monetary regime agents learn quickly, resulting in a drop in inflation persistence.

Finally, an important strand of research has demonstrated that the autoregressive term in the Phillips curve (unemployment persistence) will introduce lagged unemployment as a state variable in the reduced-form solution for inflation in the standard Barro-Gordon framework (Svensson (1997) and Lockwood *et. al.* (1998)).[5] Thus, inflation inherits the time series property of the unemployment rate. As in other models, the degree of inflation persistence in this model is fundamentally related to the nature of the monetary regime. But it also depends on the nature

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[5] Persistence in unemployment can arise in a number of different ways: for instance, high degree of state dependence (sluggishness) in labour demand because of hiring and firing costs or excessive power of insiders in wage setting combined with high correlation between employment status and insider status, etc. (Alogoskoufis and Manning (1988a, 1988b)).

of labour market institutions. The latter is an independent source of lag dynamics in inflation.

In this paper we show that the reduced-form evidence offered in support of these theories suffers from a serious lack of identification. This is because the reduced-form solution for inflation in all these models have an ARMA(p,q) representation. Yet the source of persistence differs from one model to the other. If so, estimating a univariate time series model for inflation, as is common practice, will not be able to distinguish among these alternative hypotheses.[6] Thus, here we carefully explain the problem and show that it cannot be resolved by reduced-form evidence. We illustrate this using US and UK data.

The next section reviews several popular models of inflation dynamics. We then empirically examine the consistency of US and UK inflation with the various sources of lag dynamics identified here. Our results suggest that the four potential sources of lag dynamics identified here have all been important features of the historical behaviour of inflation. The final section concludes.

SOURCES OF LAG DYNAMICS IN INFLATION

Policymakers' Willingness to Stabilize Output and Inflation Persistence

The theoretical framework consists of a stylized model with forward and backward-looking elements (see Clarida *et. al.,* 1999). The central bank is assumed to have a quadratic objective function penalizing the volatility of inflation around a (constant) target, $\tilde{\pi}_t$, and the volatility of the output

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[6] Previous work (Kozicki and Tinsley (2003) and Dossche and Everaert (2005)) has implicitly acknowledged this, but has failed to recognize the seriousness of the identification problem this poses.

gap, $\tilde{y}_t$. That is,

$$\max E_t\{\sum_{i=0}^{\infty}\beta^i[\tilde{\pi}_{t+i}^2 + \lambda\tilde{y}_{t+i}^2]\} \tag{1}$$

where $0 < \beta < 1$ is the discount factor and λ is the relative weight assigned to output gap stabilization in the loss function. The model of the economy is given by a hybrid New Keynesian Phillips curve,

$$\tilde{\pi}_t = \alpha\tilde{y}_t + \phi\tilde{\pi}_{t-1} + (1-\phi)\beta E_t\tilde{\pi}_{t+1} + u_t \tag{2}$$

where $\alpha, \phi > 0$.[7] The supply disturbance, u_t, is an i.i.d. shock with zero mean and variance σ_u^2.

The central bank's constrained optimization problem yields the following first order condition,

$$2\pi_t + \mu_t - \beta\phi E_t\mu_{t+1} = 0 \tag{3}$$

when taken with respect to the sequence of π_t, and the form:

$$2\lambda\tilde{y}_t - \alpha\mu_t = 0 \tag{4}$$

when taken with respect to the sequence of $\tilde{y}_t$. Here $\mu_t's$ are a sequence of random Lagrange multipliers. Eliminating the multipliers from these expressions gives the following Euler equation:

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[7] The model combines a rational forward-looking element with some dependence on lagged inflation. For many, this class of models represents a sort of common-sense middle ground that preserves the insights of standard rational expectations sticky-price models while allowing for better empirical fit by dealing directly with a well-known empirical deficiency of the pure forward-looking model. As a result this class of models has been widely used in applied monetary policy analysis.

$$\tilde{\pi}_t + \frac{\lambda \tilde{y}_t}{\alpha} - \frac{\beta \phi \lambda E_t \tilde{y}_{t+1}}{\alpha} = 0 \tag{5}$$

Finally, substituting the expressions for $\tilde{y}_t$ and $E_t \tilde{y}_{t+1}$ from (2) into (5) yields a semi reduced-form solution for $\tilde{\pi}_t$:

$$\left(\frac{\alpha^2 + \lambda(1+\beta\phi^2)}{\alpha^2} \right) \tilde{\pi}_t - \left(\frac{\lambda}{\alpha^2} \right) (\phi \tilde{\pi}_{t-1} + \beta E_t \tilde{\pi}_{t+1} + u_t) + \left(\frac{\beta^2 \phi(1-\phi)\lambda}{\alpha^2} \right) E_t \tilde{\pi}_{t+2} = 0 \tag{6}$$

Then the usual listing of relevant state variables (i.e., determinants of, $\tilde{\pi}_t$) would include $\tilde{\pi}_{t-1}$ and u_t, so that the solution for inflation will be of the form:

$$\tilde{\pi}_t = k_1 \tilde{\pi}_{t-1} + k_2 u_t \tag{7}$$

where k_1 and k_2 are the undetermined coefficients which are restricted to be real. This implies that $E_t \tilde{\pi}_{t+1} = k_1^2 \tilde{\pi}_{t-1} + k_1 k_2 u_t$ and $E_t \tilde{\pi}_{t+2} = k_1^3 \tilde{\pi}_{t-1} + k_1^2 k_2 u_t$. Substituting these conjectures into (6) requires that the coefficients k_1 and k_2 must satisfy the following conditions:

$$[\beta^2 \phi(1-\phi)\lambda]k_1^3 - \lambda\beta k_1^2 + [\alpha^2 + \lambda(1+\beta\phi^2)]k_1 - \lambda\phi = 0 \tag{8}$$

$$\left(\frac{\alpha^2 + \lambda(1+\beta\phi^2)}{\alpha^2} \right) k_2 - \left(\frac{\lambda\beta}{\alpha^2} \right) k_1 k_2 + \left(\frac{\beta^2 \phi(1-\phi)\lambda}{\alpha^2} \right) k_1^2 k_2 - \left(\frac{\lambda}{\alpha^2} \right) = 0 \tag{9}$$

The characteristic equation for k_1 is a cubic. Thus, an analytical solution is not available, except in the polar cases of $\phi = 0$ and $\phi = 1$.[8]

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[8] The solution is the unique value between zero and unity, which corresponds to the unique stable root (see Clarida *et. al.*, 1999).

Nevertheless, it is possible to provide an intuitive description of inflation dynamics. Notice that in this model the degree of inflation persistence, k_1, is determined by a combination of the central bank's relative preference for output stability (λ) and other structural parameters of the model. We can see that as the central bank puts relatively more weight on inflation stabilization $(\lambda \to 0)$, the speed of convergence of inflation under optimal policy increases $(k_1 \to 0)$, for a given degree of endogenous or intrinsic inflation persistence.

Beechey and Österholm (2007) track inflation persistence by estimating the autoregressive process in equation (7) above. They allow the persistence parameter k_1 to vary over time. Their estimates for the US suggest that the inflation persistence was high and more volatile during the 1970sthan in surrounding years. They attribute the high persistence observed in the 1970s to greater relative preference for output stability in the Fed's loss function. In contrast, lower persistence observed during the surrounding years is attributed to a greater willingness on the part of the Fed to stabilize inflation at the cost of output stability. This is the sense in which time variation in inflation persistence is linked to the evolution of policymakers' willingness to stabilize output.[9]

Imperfect Credibility, Learning and Inflation Persistence
The starting point for the imperfect credibility literature is that following a prolonged period of inflation an announcement by the central bank that in future the inflation target will be consistent with price stability does not

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[9] An alternative explanation for changes in inflation dynamics focuses on the possibility of a structural break in the inflation process (Cogley and Sargent (2001) and Levin and Piger (2002)). Kozicki and Tinsley (2003) and Ireland (2007) interpreted this shift as a change in the long-run inflation target of the Fed and found that once one controls for it, inflation persistence was somewhat lower.

command immediate credibility (Erceg and Levin, 2003). Agents must judge the central banks credibility of intent, that is, whether the target represents the true goal of the central bank and its credibility of action, that is, whether the central bank has the ability to meet the target even if it wants to (say, in the face of fiscal constraints). Learning takes time. And the longer the period during which inflation was high, the longer it is likely to be before the private sector is persuaded that policy has changed.

Following King (1996) and Bomfim and Rudebusch (2000) we define monetary policy credibility through the relationship between inflation targets and inflation expectations.[10] Their definition of central bank credibility is straightforward. At period $t-1$ the central bank announces its inflation target for period t, denoted by π^*. The private sector must evaluate the future reliability of this target. Overall credibility is measured by the extent to which the pronouncement of a target is believed by the private sector in the formation of their inflation expectations.

Specifically, we assume that period $t-1$ expectations of the inflation target at time t, that is, perceived inflation target denoted, π_t^p, are a weighted average of the announced target $\left(\pi_t^*\right)$ and the current periods inflation rate:

$$E_{t-1}\pi^* = \pi_t^p = \lambda\pi^* + (1-\lambda)\pi_{t-1} \tag{10}$$

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[10] Westelius (2005) on the other hand defines credibility of the policy regime through the relationship between the relative weight assigned by the central bank to inflation variability in the loss function and inflation expectations. Since the public cannot observe the true value of this parameter, they are forced to infer this based on actual inflation realization. This model also gives rise to persistence in inflation and unemployment.

The parameter λ with $0 \le \lambda \le 1$ indexes the target credibility of the central bank. For analytical convenience we assume that this learning parameter is constant in what follows.[11] If $\lambda = 1$, there is perfect credibility, and the private sectors perceives inflation target will be equal to the announced target. If $\lambda = 0$, there is no credibility, and the announced target is ignored in the formation of expectations. Intermediate values of λ represent partial credibility for the announced target.

The policymakers' loss function is:

$$L(\pi_t, u_t) = \frac{1}{2}\left[b(\pi_t - \pi^*)^2 + (u_t - ku^n)^2\right] \tag{11}$$

where $0 < b < 1$, π_t is the inflation rate in period t, u_t is the unemployment rate and ku^n represents the central bank's target level of unemployment. We assume that, $k < 1$, in which case the central bank's target unemployment rate is below the natural rate. The constraint facing the policymaker is given by an expectations augmented short-run Phillips curve:

$$u_t = u^n - \alpha(\pi_t - \pi_t^e), \alpha > 0 \tag{12}$$

where u^n is the natural rate of unemployment assumed to be a constant. The policymakers' optimal choice of inflation at time t, that is, the inflation rate that equates the marginal benefit from inflation surprise to the marginal cost is given by,

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[11] Credibility of the announced target as indexed by λ is unlikely to be exogenous. In fact, a major contribution of the learning literature is to show that credibility is established by outcome. That is, the weight that agents place on the announced target reacts to developments in the economy. If past inflation matches the inflation target, then the announced target is given more weight by the private sector in the formation of expectations of future inflation. See Erceg and Levin (2003) and Westelius (2005) for models with endogenous credibility.

$$\pi_t = \left(\frac{b}{b+\alpha^2}\right)\pi^* + \left(\frac{\alpha(1-k)}{b+\alpha^2}\right)u^n + \left(\frac{\alpha^2}{b+\alpha^2}\right)\pi_t^e \tag{13}$$

where π_t^e represents the private sector's expectations of period t inflation. The private sector in this framework knows the model including the policymaker's objective function. So the private sector expects inflation to be

$$\pi_t^e = \lambda\pi^* + (1-\lambda)\pi_{t-1} + \left(\frac{\alpha(1-k)}{b}\right)u^n \tag{14}$$

Under discretion the central bank cannot credibly manipulate inflation expectations. So the central bank takes private sector inflation expectations as given when it solves its optimization problem. Substituting (14) in (13) for π_t^e yields the reduced-form solution for inflation:

$$\pi_t = a_0\pi^* + a_1\pi_{t-1} + a_2 u^n \tag{15}$$

where $a_0 = \left(\frac{b+\alpha^2\lambda}{b+\alpha^2}\right)$, $a_1 = \left(\frac{\alpha^2(1-\lambda)}{b+\alpha^2}\right)$ and $a_2 = \left(\frac{\alpha(1-k)}{b}\right)$.

The reduced-form solution for inflation in this model too has an ARMA(p,q) representation. Yet, the source of persistence in this model is imperfect credibility $(0 \le \lambda < 1)$. Time-variation in inflation persistence can arise in this model because of learning on the part of the private sector. That is, if the announced inflation target lacks credibility, then inflation expectations will not be significantly affected. Facing imperfect credibility the policymaker perceives a quick disinflation to be extremely costly and consequently finds it optimal to gradually reduce inflation resulting in higher persistence.

The problem is that since policy is not perfectly transparent the public assesses the likelihood of a regime change from observing inflation outcomes. If actual inflation realization matches the target, then the announced target is given more weight by the private sector in the formation of expectations of future inflation. On the other hand a small reduction in inflation provides little new information and inflation expectations will therefore only adjust marginally. This of course, forces the policymaker to continue to reduce inflation gradually. It is in this manner that discretionary policy gives rise to inflation persistence.

From an empirical standpoint the learning literature predicts that a monetary regime that lacks credibility, learning by private agents can generate a significant amount of inflation persistence. In contrast, in a stable and transparent monetary regime agents learn quickly, resulting in a drop in inflation persistence.[12]

Unemployment Persistence and Inflation Dynamics

The study of commitment and discretion in monetary policy has been extended beyond the standard static framework to the realistic situation with persistence in unemployment (Svensson (1997) and Lockwood *et. al.* (1998)). With unemployment persistence there is a state-contingent inflation bias i.e., the solution for inflation will depend on lagged unemployment. Thus, inflation inherits the time series property of the unemployment rate. In what follows we review this model to stress its potential to explain inflation dynamics.

The private-sector behaviour is characterized by an expectations-augmented Phillips curve with rational expectations and unemployment persistence. That is,

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[12] Erceg and Levin (2003) formulate a DSGE model in which households and firms use optimal filtering to disentangle persistent and transitory shifts in the central banks inflation target. Their calibrated model for the US exhibits moderate persistence when monetary regime is transparent and credible and much higher persistence when agents use signal extraction to make inferences about the central bank's inflation target.

$$u_t = (1-\rho)u^n + \rho u_{t-1} - \alpha(\pi_t - \pi_t^e) + \varepsilon_t \qquad (16)$$

where $0 \le \rho < 1$, $u_t(u^n)$ is the unemployment rate (natural rate) in period t, α is a positive constant, π_t is the inflation rate and ε_t is an independently and identically distributed supply shock with mean zero and variance σ^2. The private sector has rational expectations,

$$\pi_t^e = E_{t-1}\pi_t \qquad (17)$$

where E_{t-1} denotes expectations conditional upon the realization of all variables up to and including period t-1, as well as the constant parameters of the model.

Persistence in unemployment means that the interaction between the central bank and the private sector must be modeled as a dynamic, rather than a repeated, game.[13] Thus, the central banks inter-temporal loss function is given by

$$L = E_t \sum_{t=0}^{\infty} \beta^t \left[\lambda(u_t - u^T)^2 + (\pi_t - \pi^*)^2 \right] \qquad (18)$$

where $0 < \beta < 1$ is the discount factor, $\lambda > 0$ is the relative weight on unemployment stabilization, u^T is the socially desirable unemployment rate assumed to be lower than the natural rate of unemployment and π^* is the socially desirable inflation rate.

The central bank is, for simplicity, assumed to have perfect control over the inflation rate. It sets the inflation rate in each period

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[13] With persistence the cumulative adverse effects of a given unemployment shock are greater, so the gains to stabilization are greater. On the other hand, with persistence there is greater temptation to inflate, as an increase in inflation today has perceived future as well as current benefits in terms of lower unemployment. So the central bank's optimal choice of inflation at *t* is one that equates the marginal (present value) benefit of inflation surprise with the marginal (present value) cost (see Lockwood *et. al.*, 1998).

after having observed the current supply shock, ε_t. The reduced-form solution for unemployment and inflation (see appendix for derivation) in this model is

$$u_t = (1-\rho)u^n + \rho u_{t-1} + \left(\frac{1-\beta\rho^2}{1-\beta\rho^2 + \alpha^2\lambda} \right)\varepsilon_t \qquad (19)$$

$$\pi_t = \phi_0 + \phi_1 u_{t-1} + \phi_2 \varepsilon_t \qquad (20)$$

where $\phi's$ are the undetermined coefficients. With unemployment persistence there is a state-contingent inflation bias i.e., the solution for inflation will depend on lagged unemployment. The reason is that with persistence an increase in current unemployment also increases future unemployment. Thus, an adverse supply shock $(\varepsilon_t > 0)$ not only increases inflation and unemployment today, but it also increases expectations of future inflation. This is because the private sector understands that with persistence the cumulative adverse effects of a given unemployment shock are greater. So they expect the central bank to stabilize the shock by generating inflation surprise. Thus, a temporary shock would have persistent effect on inflation.[14]

As in other models discussed above the degree of inflation persistence in this model is fundamentally related to the nature of the monetary regime (λ). But it also depends on the nature of labour market institutions (ρ). The latter is an independent source of lag dynamics in inflation.

What we have established is that the reduced-form solution for inflation in all these models have an ARMA(p,q) representation. Yet the

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[14] Notice that substituting (19) in (20) for u_{t-1} yields an ARMA(p,q) representation for inflation.

source of inflation persistence differs from one model to the other. In what follows we empirically examine the consistency of US and UK inflation data with the various sources of lag dynamics identified here.

ESTIMATION

Benchmark model

Our empirical strategy is to estimate the path of the time-varying persistence parameter. We track inflation persistence by estimating the autoregressive process in our reduced-form model, treating inflation as an observable variable and inflation persistence as an unobserved time-varying state variable. The intercept is constant in our baseline specification. The reduced-form model for inflation is couched in annual terms as in Beechey and Österholm (2007). To preserve this interpretation we estimate the model with twelve-month ended inflation data but at a monthly frequency. We estimate the following model,

$$\pi_t = \alpha + \rho\pi_{t-1} + u_t + \sum_{j=1}^{q} \theta_j u_{t-j} \qquad (21)$$

where the order-q moving-average (MA) error term is motivated by the use of year ended data.[15] Following the literature we assume that the parameter vector follows a driftless random walk:

$$\rho_t = \rho_{t-1} + \eta_t \qquad (22)$$

where $\eta_t \sim N(0, Q)$. All the parameters of the model, including the variance of η_t can be estimated jointly by maximum likelihood estimation

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[15]Our specification of the measurement equation differs from Beechey and Österholm (2007). Their measurement equation is given by $\pi_t = (1-\rho_t)\pi^* + \rho_t\pi_{t-1} + u_t + \sum_{j=1}^{q} \theta_j u_{t-j}$. Thus, the inflation target in their model is a constant. Allowing for time variation in the inflation target introduces non-linearity into their measurement equation which makes Kalman filter estimation infeasible.

(MLE) using the Kalman Filter algorithm. Provided with an estimate of the variance of η_t, the time series of the parameters ρ_t can be obtained using the Kalman filter.[16]

Data and Estimation Results

The state-space model described above is estimated with monthly observations of year-ended inflation data for US and UK (all items consumer price index) spanning the period 1955:1-2006:1 and 1956:1-2010:12 respectively. The data is collected from the Bureau of Labour Statistics and OECD respectively.

The estimated series $(\hat{\rho}_t)$ for both US and UK based on MA(12) process for the errors is plotted as the solid line in Figure 1 along with two root mean-square error bands (95% confidence interval). The pattern of time variation in inflation persistence is largely consistent with a reading of the US and UK policy history, with inflation persistence high and more volatile during the 1970s than in surrounding years. In the 1970s, the point estimate of persistence briefly exceeds one for both countries. The standard error bands are sufficiently wide for this not to be troubling. Nevertheless, Beechey and Österholm (2007)consider some reasons that could generate such a result.[17] Since the 1980s inflation persistence has been significantly less than one in both countries.

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[16] For a detailed discussion on Kalman Filter and the TVP model see Harvey (1989) and Durbin and Koopman (2001).

[17] Fan and Minford (2010) estimate an ARMA model for UK inflation for the period 1970-1978. They find that any ARMA coefficient added to a random walk is insignificant, suggesting that UK inflation first difference may well be a pure random walk during this period. They argue that in 1972 when the UK government floated the pound, there was nothing to anchor inflation expectations. Fiscal policy was highly expansionary and interest rates were held at rates that would accommodate growth and falling unemployment. To control inflation the government introduced statutory wage and price controls, which of course failed miserably.

Figure 1: Estimates of Inflation Persistence (Fixed Intercept)
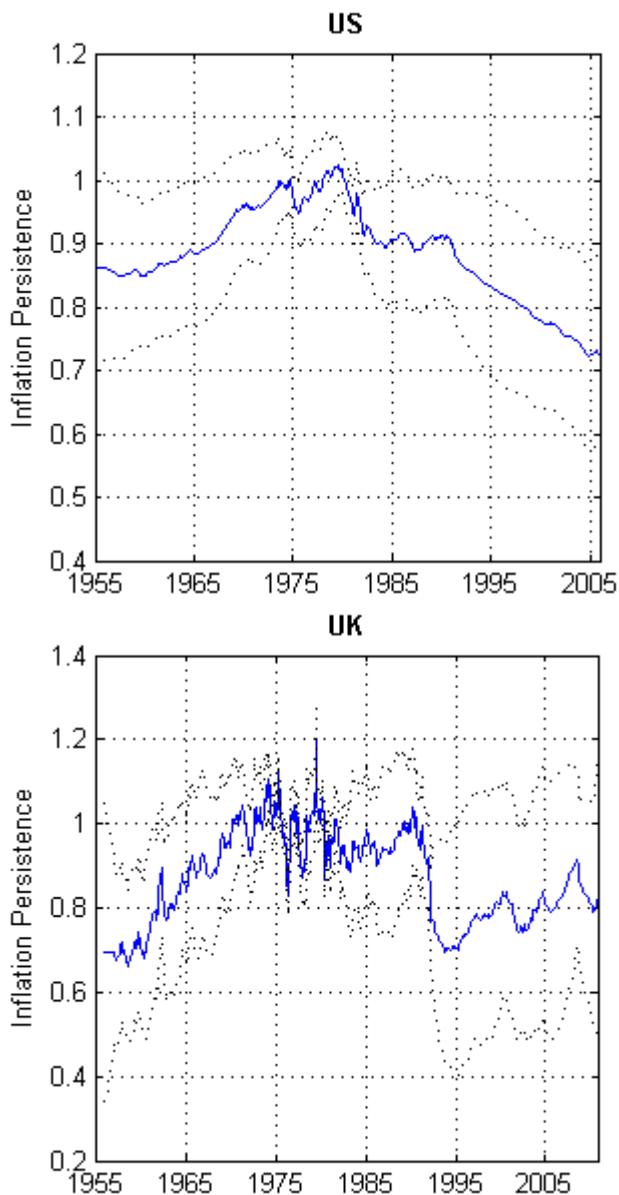
So what explains the rise and fall of inflation persistence in these countries? Beechey and Österholm (2007) attribute the rise and fall of US inflation persistence to the evolution of policymakers' willingness to stabilize output. Specifically, they argue that after Volcker became chairman in 1979 the Federal Reserve became substantially more concerned with inflation stabilization. That is, high inflation persistence of the past was due to the unwillingness to stabilize inflation rather than substantially higher inflation goals. In contrast, inflation goals were reached during the 1990s because of a greater willingness to stabilize inflation at the cost of output stability.

How robust is this conclusion? In what follows we illustrate that the reduced-form evidence offered in support of this hypothesis suffers from a serious lack of identification.

Accounting for Shifts in the Conditional Mean of Inflation

An alternative explanation for changes in inflation dynamics focuses on the possibility of a structural break in the inflation process. Levin and Piger (2002) found strong evidence for a break in the intercept and report that for many countries the persistence estimates obtained conditional on an intercept shift was found to be substantially below those conditional on no shift.[18] Kozicki and Tinsley (2003) and Ireland (2007) interpreted this shift as a change in the long-run inflation target of the Fed and found that once one controls for it, inflation persistence was somewhat lower.

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[18] In fact, this argument goes back to Perron (1990) and Hendry and Neale (1991) who pointed out that the standard Dickey-Fuller unit root test is biased towards non-rejection of the unit root hypothesis if the true data generating process includes breaks in its deterministic components.

Figure 2: Estimates of Time-Varying Intercept and Slope Coefficient
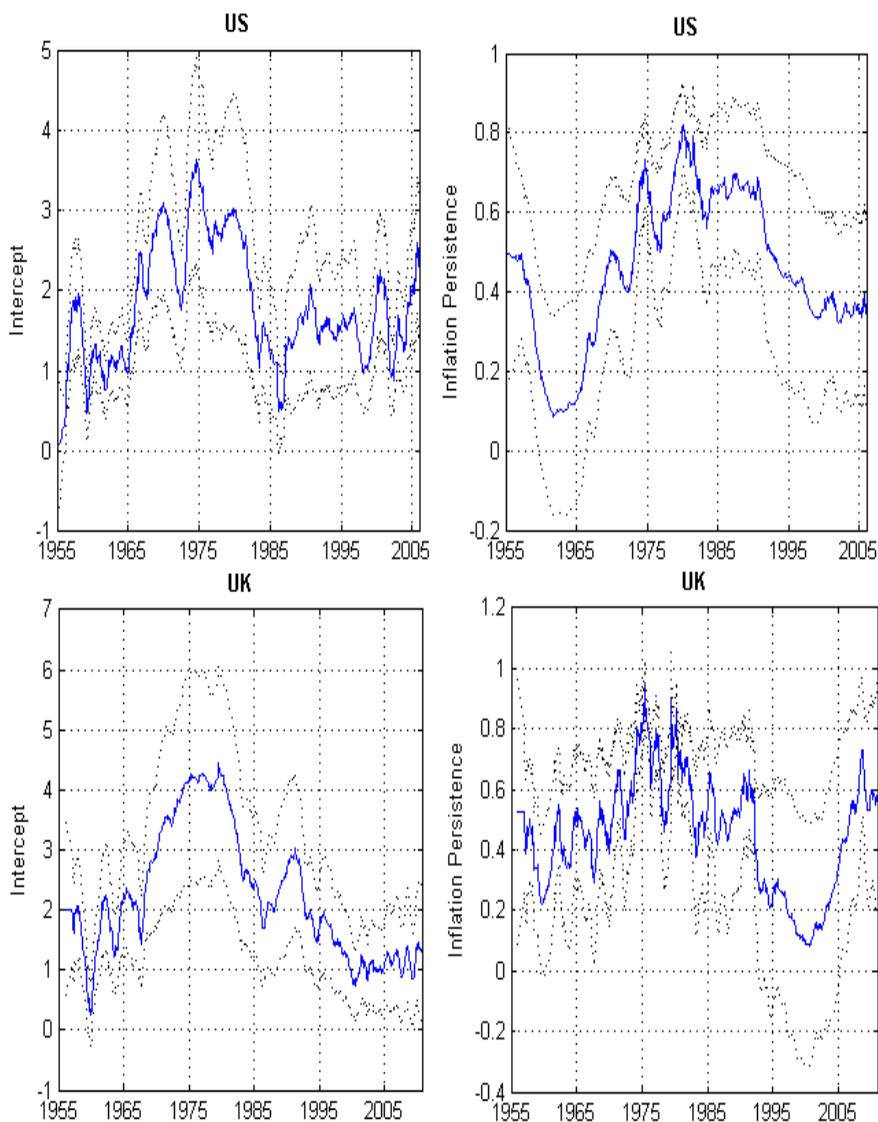
Figure 3: Estimates of the Conditional Mean of Inflation
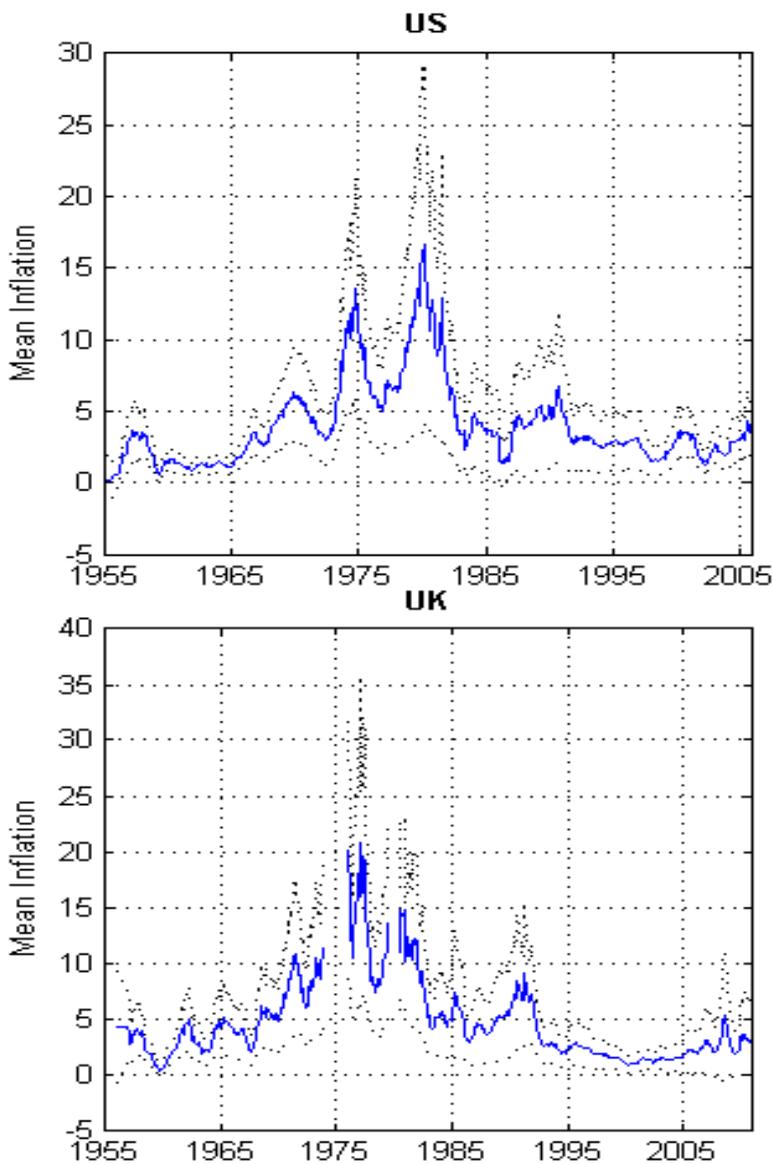
To examine this hypothesis we allow for time-variation in both the intercept and slope coefficient of our inflation equation. Specifically, we estimate model (21) but allow both the intercept and the slope coefficient to vary. Maximum likelihood estimates of $\hat{\alpha}_t$ and $\hat{\rho}_t$ for both US and UK are plotted as the solid line in Figure 2. The estimates of the intercept indicate significant variation in both countries over the sample period which is consistent with evidence reported in Levin and Piger (2002) and Ireland (2007). Figure 3 plots our estimate of the conditional mean of inflation $(E(\pi) = \alpha_t / 1 - \rho_t)$ along with standard error bands. The standard errors are derived using the delta method.[19]

The estimates suggest that the conditional mean of inflation was very low in the pre-1970s and post-1980s period, plausibly reflecting a lower inflation target in both countries. In contrast, the mean inflation rate drifted up in the 1970s, plausibly reflecting substantially higher inflation goal. More importantly, in both US and UK the persistence estimates obtained conditional on shift in the mean inflation rate are substantially below those conditional on no shift. Thus, our results lend support to the view that some of the persistence in inflation may be due to shifts in the mean inflation rate.

Testing the Credibility Hypothesis
From an empirical standpoint the credibility hypothesis predicts that a monetary regime that lacks credibility, learning by private agents can generate a significant amount of inflation persistence. In contrast, in a stable and transparent monetary regime agents learn quickly, resulting in a drop in inflation persistence. That is, the degree of inflation persistence should negatively co-vary with regime credibility. In order to empirically

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[19] The UK graph excludes data for a brief period in the 1970s because the estimated mean yields highly implausible estimates for this period. This is because the point estimate of persistence exceeds one (or is close to one) during this period.

evaluate this hypothesis we estimate the following model,

$$\pi_t = \alpha_t + \rho_t \pi_{t-1} + u_t + \sum_{j=1}^{q} \theta_j u_{t-j} \tag{23}$$

$$\alpha_t = \alpha_{t-1} + \xi_t \tag{24}$$

$$\rho_t = \rho_{t-1} + \gamma C_t + \eta_t \tag{25}$$

where the first equation represents the measurement equation and the remaining two equations are transition equations.[20] The disturbances ξ_t and η_t are serially uncorrelated disturbances with zero mean and constant variances, and are assumed uncorrelated with each other in all time periods.

The variable C_t is the month-on-month change in long-term interest rate - our proxy for credibility.[21] When credibility is low (characterized by substantial month-on-month variation in the long rate) we would expect substantial inflation inertia. In contrast, when a monetary regime is credible and inflation expectations are well anchored (characterized by lower month-on-month variation in the long rate) we would expect inflation persistence to drop significantly. These equations represent a state-space form, in which the unknown parameters, γ, σ_ξ^2 and σ_η^2 can be estimated by maximum likelihood techniques. The Kalman filter recursions can then be applied to yield optimal estimates of the

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[20] Agénor and Taylor (1993) estimate a similar model to evaluate the role of credibility in the context of stabilization policies in high-inflation countries.

[21] Goodfriend (1993) and Goodfriend and King (2005) use the behaviour of long-term interest rates as an indicator of credibility. They argue that Volcker and other FOMC members regarded long-term interest rates as a key indicator of inflation expectations and of their disinflation policy credibility. Similarly, Minford (1991) notes that the Thatcher administration in the UK also regarded long-term interest rates as an important indicator of credibility of their disinflation programme in the early 1980s.

state variable sequence. The resulting estimate of ' γ 'should be positive: lower the credibility is (substantial month-on-month variation the long rate), the higher the 'inertial' effect on inflation.

The state-space model described above is estimated with monthly observations of year-ended inflation data for US and UK from 1963:1-2010:12 because of data availability. For US long term interest rates we use 5-yearconstant maturity rate from the FRED database and for the UK we use British Government Securities 2.5% consols gross flat yield from the Office for National Statistics.

Table 1: Maximum Likelihood Estimates

	$\hat{\gamma}$	$\hat{\sigma}_{\xi}^{2}$	$\hat{\sigma}_{\eta}^{2}$
US	1.22 (0.69)	4.99×10^{-2}	9.6×10^{-4}
UK	2.19 (0.85)	5.91×10^{-2}	36.8×10^{-4}

Table 1 reports our estimates of $\hat{\gamma}$ (asymptotic standard error in parentheses). The coefficient is positive for both countries, as predicted by the credibility model, and significant. Figure 4 plots our estimates of persistence for both US and UK along with our proxy for credibility-month-on-month change in the long rate. In both countries the long rate exhibits substantial variation in the 1970s. This period was also characterized by substantial inflation inertia. In contrast, during the pre-1970s and post-1980s the long rates exhibit far less variability i.e., inflation expectations were well anchored. During these periods the degree of persistence is much lower. In sum, our results lend credence to the view that regime credibility is an important determinant of inflation inertia.

Figure 4: Estimated Persistence Coefficient and Month-on-Month Variation in Long-Term Interest Rate
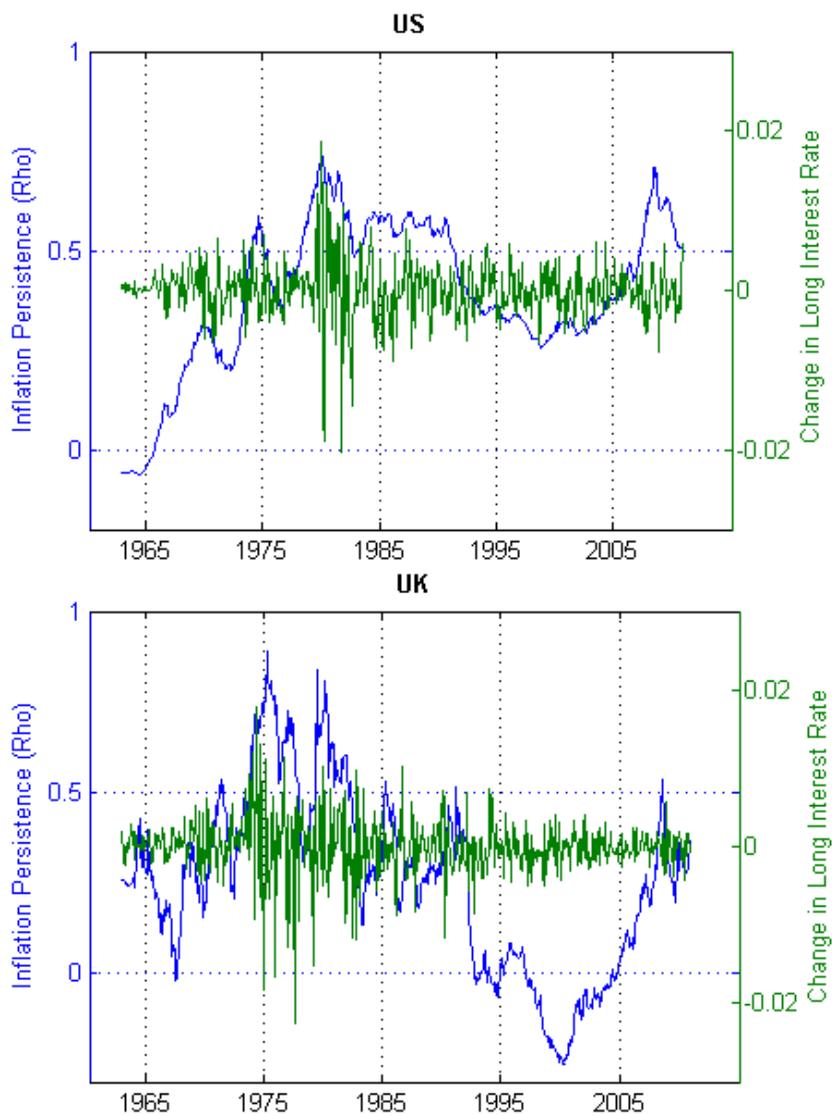
Figure 5: Estimates of Unemployment Persistence Parameter
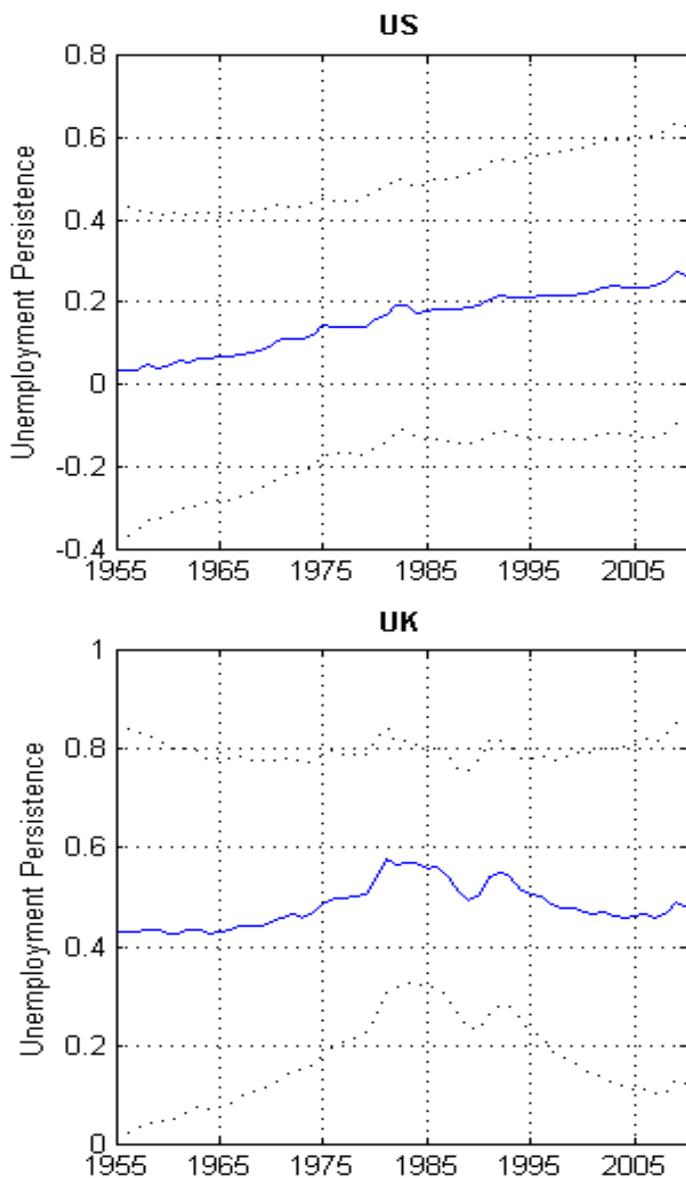
Unemployment Persistence and Inflation Dynamics

Finally, the model with unemployment persistence predicts that inflation inherits the time series property of the unemployment rate. That is, when unemployment persistence is high (because of labour adjustment costs) the model predicts that inflation persistence would be high. In contrast, as labour markets become more flexible both persistence in unemployment and inflation would fall.

In order to empirically evaluate this hypothesis we estimate the autoregressive process in our unemployment reduced-form (equation 2.3.4 above), treating unemployment as an observable variable and unemployment persistence (and the intercept) as an unobserved time-varying state variable. We estimate the following model,

$$u_t = \alpha_t + \rho_t u_{t-1} + \varepsilon_t \tag{26}$$

where both the intercept and the slope coefficient are modeled as driftless random walk.[22] Maximum likelihood estimates of $\hat{\rho}_t$ for both countries are plotted as the solid line in Figure 5.[23] The absolute degree of unemployment persistence varies across countries and our persistence ratings are consistent with other studies (see Alogoskoufis and Manning, (1988a, 1988b)). For example, US displays relatively lower degree of persistence compared to the UK. For the US, the point estimate of persistence is close to zero. This is consistent with the widely held belief

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[22] We use annual data for the unemployment rate spanning the period 1955-2010. Our data for the unemployment rate is the survey based measure as reported in the OECD's Main Economic Indicators. In the case of UK this data is not available for earlier years. For earlier years we use the data reported in Layard *et. al.* (1991) (Table A3).

[23] The theory underlying the model (19) does not suggest a moving average (MA) component. However, time aggregation as well as other measurement errors could well introduce such a component, even if the theory was true (see Alogoskoufis and Manning, 1988b). When we estimated the model with additional MA terms there was a considerable deterioration in the fit of the model.

that the US labour markets are highly flexible and that its unemployment is dominated by purely cyclical movements.

Turning to the UK, our estimates exhibit a hump-shaped pattern: it trended up from the 1960s until about 1980, then peaked and has declined since then. What explains the rise and fall of UK unemployment persistence? In the 1960s and 1970s the UK passed several laws which made labour markets more rigid; for example, the Redundancy Payment Act of 1965; the Unfair Dismissal Law of 1971; and the Employment Protection Consolidation Act of 1978 (see Minford (1991) and Siebert (1997)). With the arrival of the Thatcher government in the 1980s, labour market institutions were significantly overhauled. A series of laws throughout the 1980s weakened union power. Employment protection legislation was weakened; for example, a 1985 law said that to be protected under the laws against unfair dismissal, one had to have been employed at the job for two years, not just one. These and other such reforms made the UK labour market more flexible in the 1980s, which is consistent with the drop in unemployment persistence coefficient that we observe. Nevertheless, it is fair to say that the empirical evidence in support of this independent channel is rather weak.

CONCLUSION

Although the persistence of inflation is a central concern of macroeconomics, there is little consensus on why persistence has changed over time. We examine four potential sources of lag dynamics in inflation: the evolution of policymakers' willingness to stabilize output, shifts in the mean inflation rate, imperfect credibility and learning and unemployment persistence. We show that the reduced-form evidence offered in support of these theories suffers from a serious lack of identification. This is because the reduced-form solution for inflation in all these models have an ARMA(p,q) representation. As a result, estimating

a univariate time series model for inflation, as is the common practice, will not be able to distinguish among these alternative hypotheses. Yet econometric identification is crucial for designing institutions to combat the persistence problem. It follows that to distinguish among these alternative hypotheses it is necessary to adduce additional structural evidence about central bank's preferences, credibility of the monetary regime or about the economy's structure; or it could be indirect evidence through estimating a full structural model with all cross equation restrictions imposed from each theory, and then testing between these structures.

APPENDIX

This Appendix discusses the derivation of equations (19) and (20) in the text. Since the central bank's objective function (18) is quadratic and its constraints (16) are linear, it is possible to guess that linear-decision rules to solve the central bank's optimization problem. The central bank bases its decisions at time t solely on the state variables while inflation expectations are left to be determined by a rational expectations condition. We form the central bank's Lagrangian as:

$$E_t \left\{ \sum_{i=0}^{\infty} \beta^i \left[\begin{array}{l} \lambda(u_{t+i} - u^T)^2 + (\pi_{t+i} - \pi^*)^2 \\ + \mu_{t+i}(u_{t+i} - (1-\rho)u^n - \rho u_{t-1+i} + (\pi_{t+i} - \pi_{t+i}^e) - \varepsilon_{t+i}) \end{array} \right] \right\} \quad \text{(A1)}$$

where the μ_{t+i}'s is a sequence of random multipliers. The first-order conditions take the form:

$$2\lambda(u_t - u^T) + \mu_t - \beta\rho E_t \mu_{t+1} = 0 \quad \text{(A2)}$$

when taken with respect to the sequence of u_t's, and the form:

$$2(\pi_t - \pi^*) + \alpha\mu_t = 0 \quad \text{(A3)}$$

when taken with respect to the sequence of π_t's. Eliminating the multipliers from these expressions gives the following Euler equation:

$$\lambda(u_t - u^T) - \frac{1}{\alpha}(\pi_t - \pi^*) + \frac{\beta\rho}{\alpha} E_t(\pi_{t+1} - \pi^*) = 0 \quad \text{(A4)}$$

We now posit a linear decision rule for inflation of the form:

$$\pi_t = \phi_0 + \phi_1 u_{t-1} + \phi_2 \varepsilon_t \quad \text{(A5)}$$

If expectations formed at time $t-1$ are rational then:

$$\pi_t^e = \phi_0 + \phi_1 u_{t-1} \tag{A6}$$

Hence, the constraint imposed by the aggregate supply relation (16 in the text) yields a decision rule for u_t directly of the form:

$$u_t = (1-\rho)u^n + \rho u_{t-1} + (1-\alpha\phi_2)\varepsilon_t \tag{A7}$$

Note that decision rules are invariant so that π_{t+1} can be determined by iterating on the rule for π_t to yield the following expression:

$$\pi_{t+1} = \phi_0 + \phi_1\{(1-\rho)u^n + \rho u_{t-1} + (1-\alpha\phi_2)\varepsilon_t\} + \phi_2\varepsilon_{t+1} \tag{A8}$$

Substituting equations A5, A7 and A8 into the Euler equation A4 above, taking expectations, and equating constant terms and coefficients on the states yield values for $\phi_i's$ in terms of the underlying parameters of the model. That is, $\phi_0 = \pi^* - \dfrac{\alpha\lambda u^T}{1-\beta\rho} + \dfrac{\alpha\lambda(1-\rho)u^n}{(1-\beta\rho)(1-\beta\rho^2)}$,

$\phi_1 = \dfrac{\alpha\lambda\rho}{1-\beta\rho^2}$ and $\phi_2 = \dfrac{\alpha\lambda}{1-\beta\rho^2 + \alpha^2\lambda}$.

Finally, substituting the $\phi_i's$ in A7 and A5 yields equations (19) and (20) in the text.

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