Do Exchange Rate Regimes Matter for Inflation Persistence? Theory and Evidence from the History of UK and US Inflation

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Abstract

A well-known drawback of the New Keynesian Phillips curve is its failure to generate the high degree of serial correlation that characterized post-WWII UK and US inflation. Acknowledging the shortcoming, and in response to it, a good deal of research has proposed macroeconomic models with wage- and price-adjustment that embed inflation persistence into the behaviour of optimizing agents. The relative wage-contracting model of Fuhrer and Moore (1995) and the amended Calvo rule of Sheedy (2007) are two very good examples of this literature. Yet, more recently, another branch of the literature has cast doubt on treating serial correlation of postwar inflation as a structural feature, to be 'hardwired' into the deep structure of the economy (Levin and Piger, 2004; Benati, 2008). Instead, this branch of the literature proposes investigating the hypothesis that inflation persistence varies with changes in monetary policy regimes. This paper attempts to make a contribution to the literature by exploring theoretically and empirically the relationship between inflation persistence and exchange rate regimes using historical data on UK and US inflation from the mid-ninetieth century onwards.

In particular, the paper develops an open-economy model á la Barro-Gordon, in the context of which, it studies the effect of exchange rate regimes on inflation persistence. The model is calibrated to illustrate the response of inflation persistence to changes in a number of key exogenous variables. The calibrations confirm that, ceteris paribus, inflation persistence can vary with the exchange rate regime, thus, bearing out the main insight of the Lucas Critique. Further, the hypothesis that inflation persistence varies with the exchange rate regime is then tested empirically, employing a number of standard and unknown-break-point tests of structural change (Qu and Perron, 2007). The paper concludes that the serial correlation of inflation should not be treated as an intrinsic feature of the economy but rather as a historical outcome that is partly contingent upon the macroeconomic policy regime.

Key words: Inflation persistence, Exchange rate regimes, Asymmetric information, the Lucas Critique, Structural Stability Tests

JEL Classification: E31; E42; E52; F41

The authors are grateful to Keith Blackburn for comments and suggestions. This paper was prepared while PKG Harischandra was a research student at the University of Manchester and on study leave from the Central Bank of Sri Lanka to which he is grateful for financial support.

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May, 2008

1. Introduction

Recently, monetary policy research is increasingly focused on examining how inflation persistence affects conduct of monetary policy. For instance, the Inflation Persistence Network (IPN) in the European Central Bank is dedicated to carry out extensive research on the patterns of price setting and inflation persistence in the Euro area. Its main purpose is to examine nature and degree of inflation persistence, which is part and parcel for a proper conduct of monetary policy.[1] Similarly, many authors in recent literature highlight the importance of modelling and understanding the degree of inflation persistence. For example, Mishkin (2007), Sbordone (2007), Benati (2007), Woodford, (2006) are to name a few. Generally, researchers agree that policymakers should be more concerned about the degree of inflation persistence in setting monetary policy.

The literature on inflation persistence reveals three main stylised facts. First, as described by Persson and Tabellini (1999), average inflation rates vary greatly across countries and time, though, with a common time pattern. Most OECD countries experience low inflation rates in the 1960s and very high inflation rates in the 1970s, and starting from the late 1980s, inflation rates tend to converge to lower levels. Second, the changes in inflation rates occur at different speeds and to different extents over time. Third, due to differences in inflation adjustment process, disinflationary policy may lead to higher output costs [Fuhrer and Moore (1995)]. These stylised facts provide common grounds for researchers attempting to explain inflation persistence over time. Particularly, several studies focus on differences in speed and extent of inflation adjustment, in the context of changes in monetary/exchange rate regimes. Importantly, there is an ongoing debate on how changes in exchange rate regimes affect inflation persistence. However, only limited attempts have, so far, been made on theoretical grounds to explain the relation between inflation persistence and degree of exchange rate flexibility. The purpose of this paper is just that.

Inflation rates change across time mainly due to two reasons, a) change in the monetary policy framework (eg. shifting from fixed exchange rate regime to a floating exchange rate regime, or adopting an inflation targeting framework rather than focusing on exploiting short-run output gains etc.), and b) change in the ‘inflation process’ [Cecchetti and Debelle (2006)]. However, as claimed by Sargent (1999), these two reasons may be interrelated. Thus, several authors attempt to explain change in inflation process with reference to changes in exchange rate regimes. However, it appears that no agreement has been reached so far on the issue that; changes in exchange rate regimes are associated with changes in inflation persistence. On one hand, several studies suggest that flexible exchange rate regimes result in higher persistence due to higher monetary accommodation [For example Alogoskoufis and Smith (1991) and Alogoskoufis (1992)], on the other hand, some researchers show that changes in inflation persistence are not associated with exchange rate regimes shifts, but there are some other factors like oil price shocks, central bank reforms, outbreak of wars etc. [For example Burdekin and Siklos, (1999), Bleaney, (2001)]. Recently, several authors provide alternative interpretations for changes in inflation persistence over time. For instance, Williams

[1] See Angeloni *et al.*, (2004) for a preliminary findings of IPN.

(2006) describes changes in inflation persistence correspond to changes in inflation expectations formation process. Further, Benati (2006) highlights the effects of changes in monetary policy framework such as moving to an inflation targeting regime, on changes in inflation persistence. Similarly, Angeloni *et al.*, (2004) show that significant persistence in aggregate levels is associated with changes in monetary policy regimes.

Despite a large volume of research on inflation persistence, there remain some unexplored areas. As Ball (1995) reports "[t]he theoretical literature on monetary policy explains why inflation may be high: policymakers face a dynamic consistency problem […]. The models also explain why inflation may be low: policymakers care about their reputations[…]. The models are less helpful, however, in explaining why inflation varies between high and low levels over time" (p.330). Interestingly, even after more than a decade of Ball's comment, researchers have not been able to fill this gap, given the fact the there is only a few published articles devoted to theoretically examine inflation persistence over time. This paper, therefore, attempts to develop an analytical model that is capable of explaining inflation persistence over time.
The analytical models found in literature explaining inflation persistence broadly belong to three categories, namely, a) flexible price models, b) sticky price models, and c) sticky information models. One of the main candidates of flexible price models is Barro and Gordon (1983) framework, developed in a discretionary monetary policy framework where policymaker is free to adjust monetary policy strategies at any time. In this model, the conduct of monetary policy results in 'inflationary bias', due to policymaker's desire to expand the economy above the natural rate of employment. Subsequently, several authors adopt Barro-Gordon framework to study inflation persistence under alternative assumptions on behaviour of economic agents [see for example, Bleaney (2001), Reis (2003), and Cukierman (1992)].

Alternatively, following Taylor (1979; 1980), and Calvo (1983), sticky price models become quite common in the literature on inflation dynamics. These models are built on Taylor's standard wage contracting model or Calvo type price adjustment models. However, many authors later on find that standard specifications of sticky-price models are incapable of explaining inflation persistence, for example, Fuhrer and Moore (1995). Fuhrer and Moore provide a wage contracting model with *relative* real wage that imparts significant inflation persistence, apart from inherited persistence in the output gap process, as implied in the standard sticky price models. Subsequently, several researchers adopt sticky price models to explain inflation persistence, and specially, following pioneering work by Alogoskoufis and Smith (1991) and Alogoskoufis (1992), there has been an increasing trend examining inflation persistence in the context of shifts in exchange rate regimes [see also Obstfeld (1995)].

Because of disputes among researchers on the sticky price assumption in the standard contracting models, Mankiw and Reis (2002) propose an alternative interpretation to nominal rigidity i.e., *sticky information.* In their model prices adjust slowly due to slower dispersal of information about macroeconomic conditions. As obtaining and processing information is costly, only a fraction of firms is able to adjust prices in response to new information, while rest of the firms set prices based on 'outdated information'.

The model developed in this paper belongs to the first category i.e. Barro-Gordon framework. It mainly consists of two components viz., policy objective function and the expectations augmented Phillips curve. However, the model in this paper departs from existing literature in the way that these two components are specified. First, as the main purpose of this paper is to examine inflation persistence over different exchange rate regimes, the objective function is amended to reflect open economy characteristics. Thus, policymaker is concerned over deviations of domestic inflation rate from the foreign country, which issues reserve currency in the fixed exchange rate system. And also policy objective function includes an additional parameter to capture the effects of changes in exchange rate flexibility.

Even though the Barro-Gordon framework provides useful inputs to monetary policy analysis, some authors claim that it is less helpful to explain inflation persistence due to flexible price assumption.[2] However, attempts have been made to derive the basic Barro-Gordon framework from microfoundations with nominal rigidities [see Reis (2003)].

Second, inflation persistence is captured through innovations to the natural rate of employment, where the shock is assumed to be consisted of persistent and transitory components. The persistent component is assumed to follow an AR (1) process with an i.i.d. error term. Finally, in solving the model, two key assumptions are made on the information structure. First, the model is solved under the assumption of symmetric information where both policymaker and public share same information on the persistent component of the shock, and public forms rational expectations on the policy responses in each period. Second, information asymmetry is assumed on the part of public, where public observes shock to the natural rate only after two period lag, and forms forecasts of the inflation rate, based on the available information in the current period. However, we assume through out the paper that the type of policymaker in office and the prevailing exchange rate regimes, as common knowledge at any given time.

The paper proceeds as follows. Section 2 presents the theoretical literature on inflation persistence and exchange rate regimes, specially focusing on Barro-Gordon framework. Section 3 describes the model. Section 4 presents the solution of the model with calibration results. Section 5 describes empirical evidence and finally, section 6 concludes.

2. Literature Review

In the Barro-Gordon framework the short run trade-off between inflation and unemployment has been the central phenomenon. Barro and Gordon describe that "[t]here is an apparent contradiction because the policymaker peruses an activist policy that ends up having no desirable effects – in fact, unemployment is unaltered but inflation ends up being excessive" (p.591). Similarly, Cukierman (1992) explains that "central

[2] However, Dittmar *et al.* (2004) report that the flexible price assumption is not constraint to explain inflation persistence, when monetary authorities follow an interest rate rule. In a flexible-price model, they show that inflation generates more persistence, when the spread between real and nominal interest rates shows persistent changes.

bank may be interested in both price stability and in maintaining employment above the natural level because it is concerned with social welfare and also it partially responds to political pressure" (p.27). However, due to uncertainty on policy variables, policymakers are not always able to derive the expected outcome. Further, as described by Freidman and Phelps, a policy based on inflating the economy with the objective of increasing employment would lead to a situation where average inflation rate is higher without a positive impact on employment. Thus, policymakers face a dilemma as the overly ambitious employment target may produce an *inflationary bias* without expected results.

Therefore, a commitment to a rule has been considered to be optimal to get rid of inflation bias, along with the argument put forward by Kydland and Prescott (1977). Apparently, fixed exchange rate system is considered to be a commitment mechanism by many authors for the last couple of decades. Barro and Gordon also makes this point to a certain extent that "an exogenous shift from a regime that involved some commitment on nominal values – such as gold standard or possibly with fixed exchange rates – to one without such constraints would produce a rise in the average rates of inflation and momentary growth" (p.600). Thus, fixing the exchange rate against a low inflation reserve currency may seem to be a better commitment tool for policymakers. For example Alogoskoufis and Smith (1991) and Persson and Tabellini (1999) show that fixed exchange rates are associated with lower average inflation rates. However, the credibility of fixed exchange rate as a commitment mechanism is subject to severe scrutiny in recent literature on optimal monetary policy commitment. Because our purpose is to evaluate inflation performance in the context of different exchange rate regimes, we abstract from such analysis in this paper.

Barro-Gordon framework provides simple but useful grounds to analyse policymaker's behaviour. The basic model includes a standard specification of policy preferences and aggregate supply function in the form of an expectations augmented Phillips curve. The widely used policy objective function takes the form of a loss function which consists of employment and inflation fluctuations:

$$L_t = \frac{\lambda}{2}(\pi_t - \tilde{\pi}_t)^2 + \frac{1}{2}(y_t - \tilde{y}_t)^2, \tag{2.1}$$

where, π is domestic inflation rate and $\tilde{\pi}$ is target inflation rate, y is actual employment and $\tilde{y}$ is target level of employment, which is defined as a function of natural level of employment y^N plus a positive parameter κ, which relates to policymaker's desire to expand the economy above the natural rate ($\tilde{y} = y^N + \kappa$). The parameter λ is relative weight attached to inflation stabilization to employment stabilization.

The economy is characterised by an aggregate supply function of the following form:

$$y_t = y_t^N + \alpha(\pi_t - \pi_t^e), \tag{2.2}$$

where π^e is expected inflation, α is a positive parameter. Equations (2.2) can be used to explain the nominal wage setting process and the level of employment in the economy. For example, as Walsh (2003) describes if nominal wage contracts are set at the beginning of each period, an inflation surprise will result in reduction in real wage and subsequently more employment. On the other hand, if actual inflation is lower than the expected inflation, real wage would increase, which results in lower employment. Further, in this family of model, it is common to assume that monetary policy instrument as the money growth rate or policymaker directly chooses the inflation rate.

The literature on inflation persistence generally suggests two sources of inflation persistence, namely, a) serial correlation of money growth process and, b) serial correlation in inflation response to (serially uncorrelated) monetary policy shocks (Walsh, 2003). If the former is the only source of inflation persistence, it can explain persistence even without the assumption of price stickiness (flexible-price models), while in the latter case, inflation persistence is explained with sticky price models such as Taylor and Calvo. However, Fuhrer (2006) adopts a different terminology in explaining sources of inflation persistence in the context of NKPC models where ; a) inflation exhibits persistence if the 'driving process' is persistent (inherited inflation persistence) and, b) inflation exhibits persistence due to backward-looking terms of inflation process (intrinsic inflation persistence). The latter is consistent with the structural form of inflation persistence as explained by Gali and Gertler (1999). Further, intrinsic inflation persistence can be explained using an automatic indexation rule of changing prices, as discussed in Christiano *et al.* (2005), where firms change prices according to a degree of indexation based on past inflation.

Further into the issue of sources of inflation persistence, Angeloni *et al.*, (2004) provides a broader description of sources of inflation persistence based on a structural inflation equation of hybrid NKPC type,

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t\left(\pi_{t+1}\right) - \lambda \hat{\mu}_t + \xi_t \qquad (2.3)$$

where π is inflation, μ deviation of actual mark-up from the desired level, and ξ is exogenous mark up shock. E is the expectations operator. Accordingly, sources of inflation persistence correspond to each term in the right hand side of equation (2.3), namely, a) persistence in the mark up gap (extrinsic persistence), b) dependence on past inflation due to price-setting mechanism (intrinsic persistence), c) persistence due to formation of inflation expectations (expectations-based persistence), and d) persistence in the stochastic error term (error term persistence). However, it is noted that "these sources of persistence may be difficult to distinguish, in theory as well as empirically, since they interact in general equilibrium, and their relative importance will also very much depend on the monetary policy regime and the policy reaction function" (p.5).

Among the four sources of persistence, the expectations-based persistence has several implications, depending on the assumptions made on the nature of expectations. For example, Roberts (1995;1997) describes inflation persistence with the assumption of imperfectly rational expectations. Similarly, Ball (2000) proposes a 'less-than-fully-rational expectations model with inflation persistence, where agents form 'optimal univariate forecasts'. While his model is capable of accounting for inflation persistence across regimes, the model is based on some strong assumptions. Alternatively, Erceg and Levin (2003) present a model that generates inflation persistence without imposing imperfect rational expectations or adding arbitrary lagged inflation terms. They highlight the importance of learning process of agents in distinguishing transitory shocks to monetary policy and persistent shifts in inflation target. Further, Milani (2005) presents a model with adaptive learning that generates inflation persistence without structural persistence of inflation and rational expectations assumption.

However, in the Barro-Gordon literature inflation persistence is often introduced through persistence of shocks. For example, Cukierman (1992) describes shocks to the natural level of employment with persistent and transitory stochastic components. Further, persistent component is assumed to follow a first order Markov process, while the transitory component follows a normally distributed white noise process. In his model, inflation persistence is discussed under two alternative assumptions on information availability on the part of policymaker and the public. Under symmetric information, inflation exhibits persistence solely due to persistent shocks to the natural level of unemployment. Under asymmetric information, inflation exhibits more persistence as inflation becomes responsive to past transitory shocks. Because, public does not observe decomposition of shocks in the current period, inflation expectations respond to transitory shocks as well. That will cause policymaker's response to be sensitive to transitory shocks, as the current inflation depends on inflation expectations of public. Eventually, current inflation responds to transitory shocks, even if they do not have real effects on current employment level.

However, some authors specify the structure of shocks slightly different manner. For an example, Reis (2003) introduces a dynamic general equilibrium into Barro-Gordon framework. As the model is explicitly derived from microfoundations, the shocks are identified as shocks to the mark-up of prices over marginal costs, and they result in deviations of unemployment from the equilibrium natural rate. The underlying source of inflation persistence in his model derives from the fact that the persistent changes in the natural rate of unemployment. More precisely, because the natural rate is time varying, even policymaker does not observe it, and, therefore, forms optimal forecasts. Because of imperfect information on the natural rate and supply shocks, policymakers' optimal forecasts may not be the same as the true value. Thus, as long as optimal forecast deviates from the natural level, actual inflation will deviate from the target level. Because forecast error is persistent, inflation tends to be higher than the target level until the error diminishes. Further, if the natural level of unemployment is underestimated (which is more likely a scenario), then optimal response of the policymaker would be to set the actual inflation rate higher than the target level. According to Reis's specification, the process of updating forecasts has a geometric form and it would result in persistent deviations of inflation from the target.

Another important implication of the Barro-Gordon literature is that inflation persistence is often discussed using closed economy models. Only few studies discuss open economy extensions of Barro-Gordon model. For example, Bleaney (2001) provides some useful insights into research on inflation persistence across exchange rate regimes. His model is a straightforward extension of the Barro-Gordon model, with a slightly modified policy objective function to represent home country is concerned with deviations of domestic inflation from the inflation rate of the foreign country. Bleaney assumes supply side shocks to follow an AR (1) process, through which persistence is accounted for. However, the policy objective function of his model seems to have contradictory objectives under pegged exchange rate regimes, as the policymaker faces two inflation targets, at the same time, unless foreign and domestic inflation targets are assumed to be the same.

The following section describes the model used in the paper. Apparently, the building blocks of model are borrowed from the Barro-Gordon model. However, it can also be regarded as an open economy extension of Cukierman (1992).

3. The Model

As described above, the model employed in this paper is an open economy extension of the Barro-Gordon framework. The basic model consists of two components, namely, the policy objective function and a Phillips curve relationship. As described by several authors, the specification of the economy in the Barro-Gordon model can well be supported by nominal rigidities. For example, Reis (2003) derives the expectations-augmented Phillips curve and the policy objective function with specific microfoundations in the form of a general equilibrium model with nominal rigidities.

3.1 Policy Objective Function

The model developed in this paper deviates from previous work mainly on the specification of policy objective function. The basic Barro-Gordon framework is a close economy model which implies that policymaker minimises expected loss due to deviations of actual inflation (π) and employment (y) from the desired levels. As the purpose of this chapter is to explain inflation persistence across exchange rate regimes, the model incorporates open economy characteristics. Thus, the objective function includes an additional term relating to deviations of domestic inflation rate from the inflation rate of the foreign country, which issues reserve currency in the fixed exchange rate system. Because, policymaker is entrusted with dual objectives, an additional parameter (d) is included in order to avoid conflicting implications of the objective function. This parameter indicates the commitment of home country to maintain the peg. As the prevailing exchange rate regime is expected to play a key role in optimal policy, *d* captures the effects of change in exchange rate regimes on optimal inflation and its persistence.

Thus, policymaker minimises the present discounted value of expected losses,

$$\min \Pi = \sum_{i=0}^{\infty} \beta^i E_t L_{t+i} \ ,$$

where $\beta \in (0,1)$ is a discount factor and L_t is loss function which is quadratic in deviations of inflation and employment from target levels:

$$L_t = (1-d)\left[\frac{\lambda}{2}(\pi_t - \tilde{\pi}_t)^2 + \frac{1}{2}(y_t - \tilde{y}_t)^2\right] + \frac{d}{2}(\pi_t - \pi_t^f)^2 . \quad (3.1)$$

Equation (3.1) is the open economy objective function; π is domestic inflation rate and $\tilde{\pi}$ is target inflation rate, y is actual employment and $\tilde{y}$ is target level of employment. π^f is foreign country's inflation rate, which is assumed to follow a fixed rule. The parameter λ is relative weight attached to inflation stabilization to output stabilization. The parameter d is defined as a continuum, (i.e., $d \in [0,1]$), of which the value is dependent upon the prevailing exchange rate regime. It can accommodate for a range of exchange rate regimes including two extreme cases, namely, perfect fixity ($d \to 1$) and perfect flexibility ($d \to 0$).[3] For example, when $d \to 0$, the open economy objective function resembles to a closed economy model, as the fixed exchange rate system is completely abandoned.

The first term in brackets in the right hand side of equation (3.1) indicates costs associated with deviations of actual inflation from the target level. Similarly, the second term in brackets implies costs due to deviations of employment from the target level. The target level of employment is described as a function of natural level of employment y^N plus a positive parameter κ, which relates to policymaker's desire to expand the economy above the natural rate, i.e. $\tilde{y} = y^N + \kappa$. There are several interpretations for the existence of $\kappa > 0$, in policy objective function. Walsh (2003) describes two alternative interpretations, a) presence of labour market imperfections (such as wage tax, monopoly unions, monopolistic competition sectors etc.) which result in employment to be inefficiently low and, b) political pressure on central bank, because economic expansions would increase re-election prospects.[4] The term in parentheses in the extreme right of equation (3.1) relates to deviation of domestic inflation from inflation rate of the foreign country.

3.2 Specification of the economy

The short-run behaviour of the economy is described by an expectations-augmented Phillips curve, which implies that deviation of actual employment from the natural level is positively related to inflation surprises:

[3] Apart from the two extreme cases, the model may be used to account for some other related issues such as optimal exchange rate bands (see Cukierman *et al.*, 2004). In their model, exchange rate bands can also work as either of the two extreme cases depending on private agents' expectations on the reputation of policymaker. If public expects perfect reputation, exchange rate band would be seen as a perfect peg (*a zero band width*). On the contrary, if public expects no perfect reputation, then band would deviate within a certain width or perhaps it would go to the other extreme i.e., perfect flexibility (*a band of infinite width*). Thus, policymaker's emphasis over the trade off between flexibility of the exchange rate policy and cost of variability in the nominal exchange rate would really play a key role.

[4] See also Cukierman (1992) and Reis (2003).

$$y_t = \bar{y}^N + \alpha\left(\pi_t - \pi_t^e\right), \tag{3.2}$$

where π^e is expected inflation, α is a positive parameter, and $\bar{y}^N$ is mean natural level of employment (a positive constant). Following Cukierman (1992), the natural rate of employment is defined as follows:

$$y_t^N = \bar{y}^N - u_t - \varepsilon_t, \tag{3.3}$$

where u_t is the persistent component of the shocks and assumed to follow an AR(1) process and ε is a transitory stochastic variable with $E(\varepsilon_t) = 0$ and $Var(\varepsilon_t) = \sigma_\varepsilon^2$. The persistent component is thus specified as:

$$u_t = \delta u_{t-1} + \upsilon_t, \qquad \upsilon_t \sim N\left(0, \sigma_\upsilon^2\right). \tag{3.4}$$

where $\delta \in [0,1]$ which captures persistence in the natural rate, and υ_t is a normally distributed innovation term. This specification implies that the natural level of employment exhibits stochastic fluctuations due to non-monetary factors, which is a widely expected phenomenon in empirical literature on the natural rate. Further, u_t can represent shocks due to changes in productivity, or coming from disutility of labour supply.

3.3 Policy Instrument

For simplicity, we assume that policymaker directly chooses the inflation rate, given current economic conditions. Initially, Barro and Gordon assume money growth as the policy instrument. However, most authors generally agree that money growth rate is closely linked to inflation rate. Cukierman (1992) defines the rate of inflation is equal to the money growth rate, abstracting from real shocks, growth and changes in velocity. Further, Walsh (2003) describes that distinction between policy instruments would be immaterial for the purpose of explaining determinants of average inflation rates, "[g]iven the focus on inflation, it will also be convenient at times simply to treat the inflation rate as the policy instrument" (p.370). However, it does make an impact in the discussion of stabilization policy.

4. Solving the Model and Analysis

The model presented above is solved under two key assumptions on information availability. First, the model assumes that policymaker and the public share the same information set in each period. Policymaker solves for optimal rate of inflation in order to minimise the loss function, given current period's shocks and the constraint posed by the economy. Similarly, public forms rational expectations independent of the past inflation rates, having obtained the same information on the variables affecting the current policy choice. Therefore, the model reduces to the basic Barro-Gordon framework, in which policymaker and public solve a succession of ‘one-shot’ problems in each period.

Second, in the presence of asymmetric information policymaker is assumed to posses up-to-date information over the value of natural rate of employment, and its decomposition into persistent and transitory components. However, public is assumed to obtain information over the shocks to natural rate after two periods. Nonetheless, in both cases, information over prevailing exchange rate regime (d) and the type of policymaker in office (λ) is assumed to be publicly available in each period.

4.1 Inflation Persistence under Symmetric Information

Due to symmetric information assumption, all variables in the objective function is in the policymaker’s information set in period t, therefore, expectation operator is omitted from the objective function. Similarly, as Walsh describes, even if policymaker aims at minimising the present discounted value of expected losses, the objective function of the basic Barro-Gordon framework does not imply a link between current decisions and future periods. By inverting the objective function to solve as a maximisation solution, and also using equations (3.2) and (3.3), the policy objective function is written as follows:

$$\Lambda = (1-d)\left[-\frac{\lambda}{2}(\pi_t)^2 - \frac{1}{2}\left(\alpha\left(\pi_t - \pi_t^e\right) + u_t + \varepsilon_t - \kappa\right)^2\right] - \frac{d}{2}\left(\pi_t - \pi_t^f\right)^2,$$

where domestic target inflation rate is normalised to zero for simplicity $(\tilde{\pi} = 0)$ and the definition of target output $\tilde{y} = y^N + \kappa$ is also used.

Given policymaker’s optimal choice and private agents’ rational expectations, a reduced form equilibrium inflation rate is derived. Based on the equilibrium inflation rate, the inflation persistence coefficient is obtained. The first-order condition of the maximisation problem implies semi reduced form of optimal rule for setting inflation:

$$\pi_t = \frac{(1-d)\left[\alpha^2 \pi_t^e + \alpha\left(\kappa - u_t - \varepsilon_t\right)\right] + d\pi_t^f}{(1-d)\left(\lambda + \alpha^2\right) + d}. \qquad (4.1)$$

As the optimal policy depends on inflation expectations of public, assuming rational expectations, the public’s inflation expectations are determined by unconditional expectation of equation (4.1), also using the fact that $E(u_t) = \delta u_{t-1}$:

$$\pi_t^e = \frac{(1-d)\alpha(\kappa - \delta u_{t-1}) + d\pi_t^f}{(1-d)\lambda + d} > 0, \qquad (4.2)$$

The reduced form optimal inflation rate is derived by substituting equation (4.2) back into equation (4.1):

$$\pi_t = \frac{\alpha(1-d)(\kappa - \delta u_{t-1}) + d\pi^f}{(1-d)\lambda + d} - g\alpha(1-d)(\upsilon_t + \varepsilon_t), \qquad (4.3)$$

where,

$$g = \left[(1-d)(\lambda + \alpha^2) + d\right]^{-1}.$$

Equation (4.3) implies that policymaker responds to shocks by accommodating more of the persistent component of the shock (δu_{t-1}), and less of the transitory component (ε_t). Further, because the persistent component is dependent upon the degree to which shocks are autocorrelated, the more persistent shocks are more strongly accommodated. This result is consistent with those in the literature [see for example Bleaney (2001)].
Further, equation (4.3) implies the relation between the optimal inflation rate and the degree of exchange rare flexibility. For example, the optimal inflation rate under a perfectly fixed exchange rate regime (i.e., when $d \rightarrow 1$) is given by,

$$\pi_t = \pi_t^f , \qquad (4.4)$$

where policymaker is fully committed to maintain the inflation rate of the foreign country. On the other hand, under perfectly flexible exchange rate regime (i.e., when $d \rightarrow 0$), the optimal inflation rate yields,

$$\pi_t = \frac{\alpha(\kappa - \delta u_{t-1})}{\lambda} - \left(\frac{\alpha}{\lambda + \alpha^2}\right)(\upsilon_t - \varepsilon_t), \qquad (4.5)$$

where policymaker optimally sets the inflation rate contingent on other parameters of the model. For instance, if policymaker pursues a overly ambitious employment target, i.e., a higher κ, the inflation rate would be higher. On the other hand, if policymaker places higher weight on inflation stabilization (i.e., higher λ), equation (4.5) implies a lower inflation rate. More importantly, the degree of autocorrelation of the persistent component of the shocks would impact on the optimal inflation rate in the flexible exchange rate regime.

4.1.1 Optimal inflation rate when targeting the foreign country's inflation rate

In the similar fashion as described above, the model can be solved for targeting the foreign country's inflation rate. Then the optimal inflation rate reduces to:

$$\pi_t = \pi^f + \frac{\alpha(1-d)(\kappa - \delta u_{t-1})}{[(1-d)\lambda + d]} - g\alpha(1-d)(\upsilon_t + \varepsilon_t). \qquad (4.3a)$$

where $g = \left[(1-d)(\lambda + \alpha^2) + d\right]^{-1}$.

It implies that, in the absence of shocks to natural rate, there is one-to-one relationship between domestic inflation rate and that of the foreign country, irrespective of the degree of exchange rate flexibility. This contradicts with previous results where home country pursues its own domestic inflation target, in which the relation between domestic and foreign inflation rates determined by the degree of exchange rate flexibility. However, optimal inflation rate can deviate from the foreign inflation rate due to persistent and transitory shocks to employment.

Further, when considering the role of '*d*', under perfectly flexible exchange rate regime ($d \to 0$), optimal domestic inflation rate reduces to,

$$\pi_t = \pi^f - \frac{\alpha\kappa\delta}{\lambda} u_{t-1} - \frac{\alpha}{(\lambda + \alpha^2)}(\upsilon_t + \varepsilon_t),$$

which implies that when the domestic economy is hit by shocks, the domestic inflation rate can be larger than the foreign country's inflation rate to the extent that the shock is persistent. The transitory components of the shock also result in deviations in the domestic inflation rate. On the other hand, the result implies equality between the domestic and foreign inflation rates under perfectly pegged exchange rate regime ($d \to 1$), as shown in equation (4.4).

4.1.2 Optimal Depreciation Rate

Assuming purchasing power parity holds, equation (4.3a) can be used to express the optimal depreciation rate;

$$\dot{s}_t = \frac{\alpha(1-d)(\kappa - \delta u_{t-1})}{[(1-d)\lambda + d]} - g\alpha(1-d)(\upsilon_t + \varepsilon_t),$$

which refers to the effects of shocks on the optimal inflation rate. A negative productivity shock is associated with a higher optimal inflation rate which results in depreciation of the domestic currency. More persistent shocks result in larger depreciation. Further, the impact of shocks is also determined also by the degree of exchange rate flexibility.

4.1.3 Equilibrium under Discretion and Commitment

Equation (4.3) implies that on average a discretionary policy (i.e., when $d \to 0$) would yield a positive inflation rate,

$$\pi_t = \frac{\alpha\kappa}{\lambda}. \qquad (4.6)$$

which is increasing in unanticipated inflation (α), and the incentive of the policymaker to expand the economy (κ), and decreasing in weight on inflation stabilization. This gives an equilibrium inflation rate under a perfectly flexible exchange rate policy.

However, this outcome is achieved at the expense of loss of credibility as rational agents expect policymaker's incentive to inflate the economy in absence of a commitment to maintain a perfectly fixed exchange rate policy.

On the contrary, if policymaker is committed to credibly maintain the fixed exchange rate (i.e., when $d \to 1$), average domestic inflation rate would become equal to foreign inflation rate, as shown in equation (4.4).

A comparison between equations (4.4) and (4.6) would yield important implications. The equilibrium inflation rate under discretion would definitely be positive, where as under commitment it could be either zero or closer to zero, depending on the inflation rate of the foreign country. If the foreign country is credibly committed to maintain a zero inflation rate, equilibrium inflation rate under commitment would be preferred to discretionary outcome. However, the choice between discretion and commitment to a rule becomes harder in this context, as by committing to a fixed exchange rate, policymaker loses the control of employment stabilization. However, as described by Persson and Tabellini (1990) "[s]imple rules means to abandon activist stabilization. And discretion means to accept a higher average equilibrium rate of inflation. Which of these costs is higher generally depends on the parameters in the economy" (p.25).

4.1.4 Inflation Persistence Coefficient under Symmetric Information

This section derives inflation persistence coefficient as the correlation coefficient of current and past inflation rates. Taking one period lag of equation (4.3) and also using the result $\delta u_{t-2} = u_{t-1} - \varepsilon_{t-1}$:

$$\pi_{t-1} = \frac{\alpha(1-d)(\kappa - u_{t-1} + \upsilon_{t-1}) + d\pi^f}{(1-d)\lambda + d} - g\alpha(1-d)(\upsilon_{t-1} + \varepsilon_{t-1}). \qquad (4.7)$$

It follows that unconditional expectation of equation (4.3) yields,

$$E_t(\pi_t) = \frac{(1-d)\alpha\kappa + d\pi_t^f}{(1-d)\lambda + d}. \qquad (4.8)$$

Using equations (4.3), (4.7) and (4.8), the covariance of current and past inflation is derived using the result: $Cov(\pi_t, \pi_{t-1}) = E[\pi_t - E(\pi_t)]\,[\pi_{t-1} - E(\pi_t)]$,

$$Cov(\pi_t, \pi_{t-1}) = \delta\left(\frac{\alpha(1-d)}{(1-d)\lambda + d}\right)^2 \sigma_u^2. \qquad (4.9)$$

Further, using equation (4.3), the variance of the optimal inflation rate is derived as,

$$Var(\pi_t) = \alpha^2 \sigma_u^2 (1-d)^2 \left(\delta^2 \left(\frac{1}{(1-d)\lambda + d} \right)^2 + g^2 \left((1-\delta^2) + \frac{\sigma_\varepsilon^2}{\sigma_u^2} \right) \right). \qquad (4.10)$$

Equations (4.9) and (4.10) yield the correlation coefficient of current and past inflation:

$$\rho^{SI}_{(\pi_t, \pi_{t-1})} = \frac{\delta}{[(1-d)\lambda + d]^2 \left(\frac{\delta^2}{[(1-d)\lambda + d]^2} + \frac{(1-\delta^2) + \sigma}{[(1-d)(\alpha^2 + \lambda) + d]^2} \right)} \qquad (4.11)$$

where $\sigma = \sigma_\varepsilon^2 / \sigma_u^2$ (variance ratio)

This implies that when $\delta = 0$, equation (4.11) becomes zero, i.e., $\rho^{SI}_{(\pi_t, \pi_{t-1})} = 0$, so the model explains no inflation persistence. When $\delta > 0$, inflation exhibits persistence depending on the parameters α, λ, d, and the variance ratio. The inflation persistence coefficient is expected to be positively related to changes in α, and negatively related to changes in λ and d. Further, it turns out that the persistence coefficient is negatively related to changes in the variance ratio. An increased volatility in the transitory component of the shock (σ_ε^2) would result in increased variance ratio (having σ_u^2 unchanged), and eventually less persistence in the inflation process. Intuitively, as ε_t is unanticipated by the public, its increased volatility would not result in higher inflation expectations, and that would not exacerbate the pressure on persistent of the inflation process. By contrast, an increase in σ_u^2 would result in more volatility of the persistent component , and having anticipated it by the public, would result in more inflation persistence.

Further, the relation between parameters d and ρ has several implications. Equation (4.11) is turned out to be decreasing in d, implying more constraining exchange rate regimes may result in lower inflation persistence. Further, for extreme values of d i.e., when $d \to 0$ (i.e., perfect flexibility), persistence coefficient reduces to,

$$\rho^{SI}_{(\pi_t, \pi_{t-1})} = \frac{\delta}{\lambda^2 \left(\left(\frac{\delta}{\lambda} \right)^2 + \frac{(1-\delta^2) + \sigma}{(\alpha^2 + \lambda)^2} \right)}, \qquad (4.12)$$

which implies a larger coefficient value than in equation (4.11). On the contrary, when $d \to 1$ (i.e., perfect fixity), persistent coefficient is independent of other parameters of the model [$\rho^{SI}_{(\pi_t, \pi_{t-1})} = \delta \Big/ \left(1 + \frac{\sigma_\varepsilon^2}{\sigma_u^2} \right)$]. Figure 1 depicts the response of inflation persistence coefficient to varying degrees of autocorrelation of socks and the degree of exchange rate flexibility. The graphs through out the paper (if not otherwise mentioned) are based on the parameter values; $\alpha = \lambda = 1$. And in the symmetric information case, the variance ratio is assumed to be 0.5. The value of α is more or less justified given the econometric evidence, which suggests that it takes values in the range of between 0.8 and 2. In case of λ , the model assumes that policymaker is equally concerned with inflation and employment stabilization. The values selected for variance ratio is consistent with the early work [see Reis (2003)]. However, it is noted that there are no established priors about the values of these components can take.

Result 1: *The degree of inflation persistence is positively correlated with both the degree of exchange rate flexibility and the degree of autocorrelation of shocks to natural rate. However, the response of inflation persistence to increased degree of exchange rate flexibility is lessoned for largely autocorrelated shocks.*

As shown in Figure 1, inflation persistence declines as $d \to 1$(i.e., moving towards more constraint exchange rates). It can also be observed that larger values of degree of autocorrelation (i.e., higher δ) result in higher inflation persistence.

Figure 1: Inflation persistence and degree of exchange rate flexibility: Symmetric Information

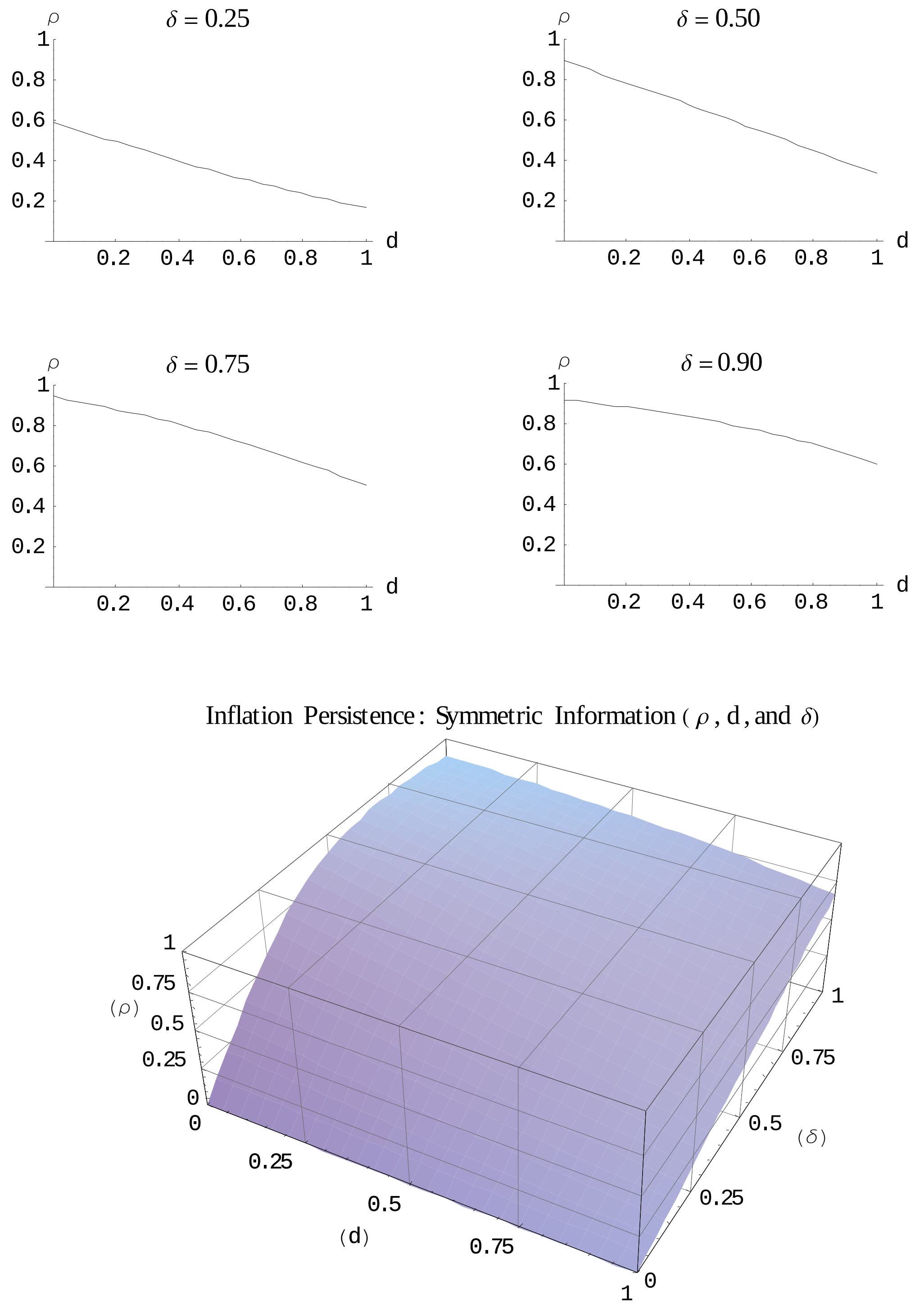
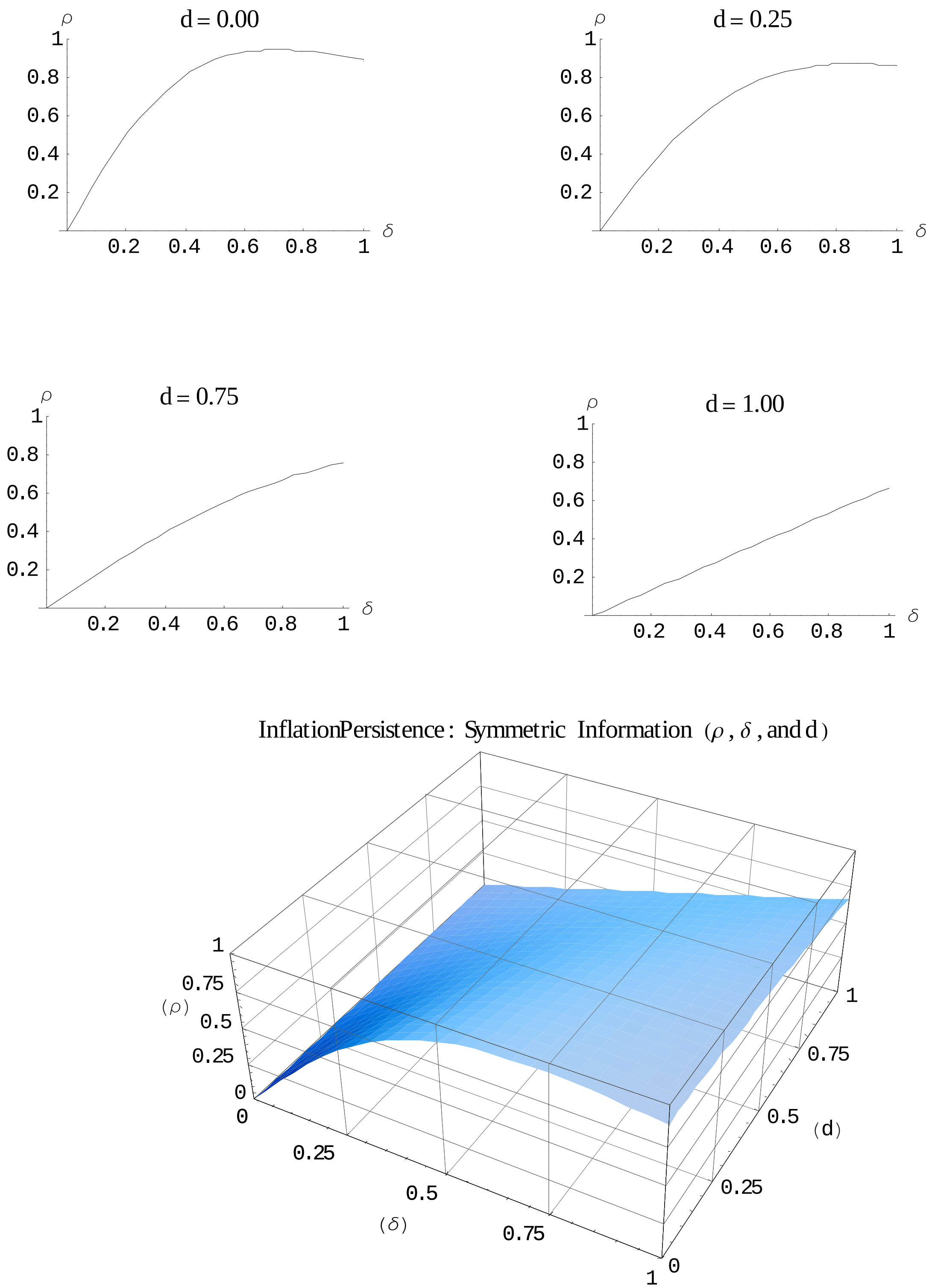


Figure 2: Inflation persistence and degree of autocorrelation of supply shocks: Symmetric Information



However, the response of inflation persistence as $d \to 1$, is not linear for all values of δ. As can be seen in Figure 1, the path of inflation persistence takes the shape of a convex curve for values $\delta < 0.50$, where as it turns out be concave for values $\delta > 0.50$. Similarly, Figure 2 shows how inflation persistence responds to degree of autocorrelation of shocks for certain values of *d*. Again for lower values of d, persistence coefficient responds well, however, as $d \to 1$, the response declines. Generally, inflation persistence shows marked response for lower values of δ or d and the response declined as these values get close to one.

Further, inflation persistence shows expected response for other parameters of the model. For example, higher values of α are associated with more persistent inflation, and again persistence coefficient responds less to degree of exchange rate flexibility for largely autocorrelated shocks. On the other hand, for larger values of λ, inflation persistence tends to be more rigid, irrespective of the degree of exchange rate flexibility, and other parameters of the model. However, the degree of autocorrelation of shocks determines the level of persistence. Further, the model implies that when transitory component of shock is more volatile than the persistent component, inflation persistence tends to be lower.

Another important implication of equation (4.11) is that inflation persistence in home country is independent of that of foreign country, even if the peg is maintained perfectly. This is in stark contrast to the result derived in Bleaney (2001), as his model implies that home country would have lower inflation persistence only if the foreign country has lower persistence.

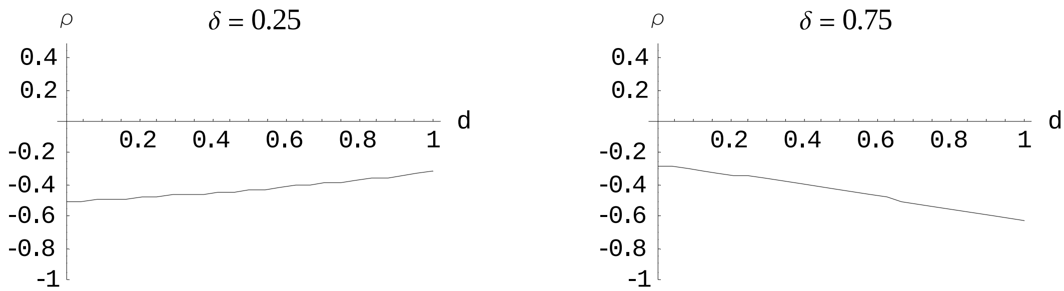
4.1.5 Comparative Statics under Symmetric Information

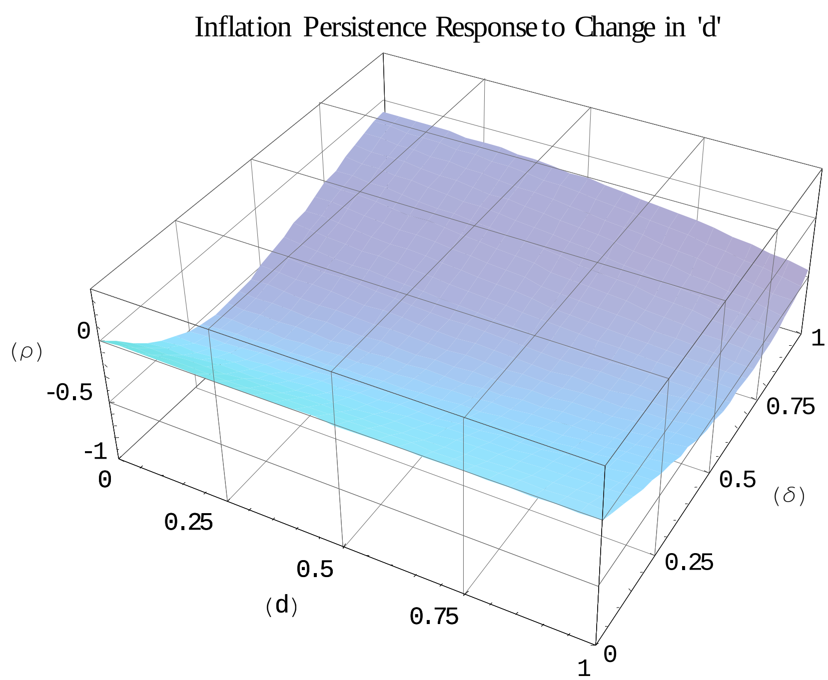
Figures 3 and 4 show the behaviour of inflation persistence to a change in the degree of exchange rate flexibility and the degree of autocorrelation of shocks, respectively.

Result 2: *The response of inflation persistence to a change in the degree of exchange rate flexibility is asymmetric given the value of* δ. *For lower values of* δ *(e.g.,* $\delta < 0.40$*) an increase of d results in more persistence, and for higher values of* δ *(e.g.,* $\delta > 0.60$ *an increase of d yields lower persistence.*

Figure 3 shows the path of inflation persistence coefficient to a change in the degree of exchange rate flexibility. When the shock to natural rate is less autocorrelated, any attempt to increase the degree of exchange rate flexibility would yield counter productive results. On the other hand, for highly autocorrelated shocks, increased constraint of the exchange rate would result in more persistence.

Figure 3: Inflation persistence response to a change in the degree of exchange rate flexibility: Symmetric Information

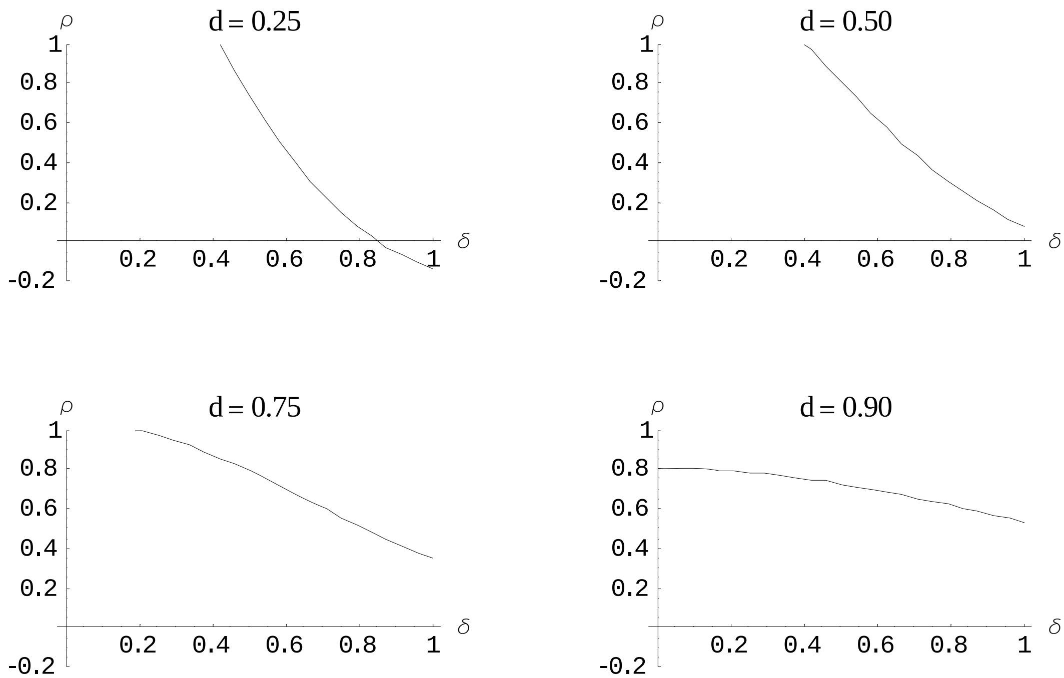




Result 3: *The response of inflation persistence to a change in the degree of autocorrelation of shocks yields inconclusive results. The path of inflation persistence is declining as* $\delta \to 1$*, and becomes less responsive for higher values of d. However, as shown in Figure 2, the relation between inflation persistence and the degree of autocorrelation of shocks shows expected results.*

As shown in Figure 4, the initial positive response of inflation persistence tends to decrease at an decreasing rate, as the degree of exchange rate flexibility increases. At the perfectly pegged exchange rate, inflation persistence is constant irrespective of the degree of autocorrelation.

Figure 4: Inflation persistence response to a change in the degree of autocorrelation of supply shocks: Symmetric Information



4.2 Inflation Persistence under Asymmetric Information

Following Cukierman (1992), the information advantage of policymaker is characterized by the assumption that public observes actual employment and the decomposition of transitory and stochastic components of shocks, with a two period lag. In contrast, policymaker possesses up-to-date information on the current state of the natural level and its decomposition, which enables to forecast current and future natural levels of employment more precisely and thereby stabilize real fluctuations in employment.

Substituting equations (3.2) and (3.3) into policy objective function:

$$E_t \sum_{i=0}^{\infty} \beta^i \left\{ (1-d)\left[\frac{\lambda}{2}(\pi_t)^2 + \frac{1}{2}\left(h_t - \alpha\left(\pi_t - \pi_t^e\right)\right)^2 \right] + \frac{d}{2}\left(\pi_t - \pi_t^f\right)^2 \right\}, \tag{4.13}$$

where, $h_t \equiv \tilde{y}_t - \bar{y}^N + u_t + \varepsilon_t \equiv H + u_t + \varepsilon_t$. (4.14)

The parameter *H* is assumed to be positive because policymaker perceives the natural level of employment to be too low due to distortionary taxes, and also policymaker partially responds to political pressures so that desired level of employment is kept above the natural level. The equilibrium condition is characterised by strategic responses of policymaker and the public. Thus, policymaker chooses the inflation rate, given expectations of the public, in order to minimise the expected loss due to deviations of inflation and employment from target levels. Similarly, public forms expectations, given their perception of the response of policymaker, in order to minimise the *conditional mean forecast error*. Because of this strategic interaction between the optimal policy of policymaker, and optimal inflation forecasts of public, the solution of the model needs to be characterised simultaneously, which is done by using the method of undetermined coefficients.

4.2.1 Solving for equilibrium

Policy objective function implies that optimal inflation depends on *h*, π^e and π^f in the current period, and currently expected next period's values of *h*, π^e, π^f and π. The reason why only next period's values are considered, is because public observes the values of u_t after two periods, and therefore current inflation is needed only for forecasting $t+1$ inflation rate. Thus, inflation expectations from $t+2$ and onwards are not influenced by the choice of π_t. Therefore, the optimal value of π_t depends on h_t, π_t^e, π_t^f and period *t* expectations on h_{t+1}, π_{t+1}^e and π_{t+1} (assuming foreign country is assumed to follow a fixed rule). The solution of policymaker's decision strategy is described in the following linear function:

$$\pi_t = K_1 h_t + K_2 \pi_t^e + K_3 \pi_t^f + K_4 E_{G,t} h_{t+1} + K_5 E_{G,t}\left(\pi_{t+1} - \pi_{t+1}^e\right) \tag{4.15}$$

where $K_i, i = 1,...,5$ are coefficients to be determined. The subscript 'G' refers to expectations of policymaker. In what follows, we assume that in the beginning of each period, public enters into nominal wage contracts given their inflation expectations, based on information set I_t, which includes information on employment level and persistent component of natural level up to and including $t-2$, and past inflation rates up to and including π_{t-1}.

Accordingly, policymaker chooses current inflation rate, given public's expectations, after observing current level of employment and after observing the persistent and transitory components of the natural level.

Taking equation (4.15) one period forward:

$$E\left[\pi_{t+1} \mid I_{t+1}\right] \equiv \pi_{t+1}^e = K_1 E\left[h_{t+1} \mid I_{t+1}\right] + K_2 \pi_{t+1}^e + K_3 \pi_{t+1}^f + K_4 E\left[E_{G,t+1} h_{t+2} \mid I_{t+1}\right] + K_5 E\left[E_{G,t+1}\left(\pi_{t+2} - \pi_{t+2}^e\right) \mid I_{t+1}\right]. \tag{4.16}$$

Using equation (4.14), the expected value of the third term in the right-hand side of equation (4.16) is written as:

$$E[h_{t+2} \mid I_{t+1}] = H + \delta^3 u_{t-1} + \delta^2 E[\upsilon_t \mid I_{t+1}] \tag{4.17}$$

Also, given public information set in period $t+1$, expected value of the last term in equation (4.16) is equal to zero:

$$E\left[E_{G,t+1}\left(\pi_{t+2} - \pi^e_{t+2}\right) \mid I_{t+1}\right] = 0 \tag{4.18}$$

Substituting (3.4) into (4.15), using the result in (4.14):

$$\pi_t = K_1\left(H + \delta u_{t-1} + \upsilon_t + \varepsilon_t\right) + K_2\pi^e_t + K_3\pi^f_t + K_4 E_{G,t}\left(H + \delta^2 u_{t-1} + \delta\upsilon_t\right) + K_5 E_{G,t}\left(\pi_{t+1} - \pi^e_{t+1}\right).$$

Rearranging yields:

$$\pi_t - K_1\left(H + \delta u_{t-1}\right) - K_2\pi^e_t - K_3\pi^f_t - K_4\left(H + \delta^2 u_{t-1}\right) - K_5 E_{G,t}\left(\pi_{t+1} - \pi^e_{t+1}\right) = K_1\left(\upsilon_t + \varepsilon_t\right) + K_4\delta\upsilon_t . \tag{4.19}$$

Equation (4.19) implies the basic informational problem of the public. Public is interested in getting as accurate as possible an estimate of υ_t but observes only a mixture of this variable with other stochastic variable, as shown in the left hand side of the equation. However, according to the assumptions on information set, public knows all the terms in the left-hand side of equation (4.19), except for $E_{G,t}\left(\pi_{t+1} - \pi^e_{t+1}\right)$. Following Cukierman, we assume, for simplicity, that public assumes this expression is equal to zero. This assumption may restrict the rationality of public's expectations formation procedure.

From equation (4.19),

$$E[\upsilon_t \mid I_{t+1}] = \frac{\left(K_1 + \delta K_4\right)\sigma^2_\upsilon}{\left(K_1 + \delta K_4\right)^2 \sigma^2_\upsilon + K_1^2 \sigma^2_\delta}\left[\pi_t - \omega(t)\right], \tag{4.20}$$

where $\omega(t) = K_1\left(H + \delta u_{t-1}\right) - K_2\pi^e_t - K_3\pi^f_t - K_4\left(H + \delta^2 u_{t-1}\right).$ (4.21)

Now, the problem of the public, as implied in equation (4.20), is to obtain the best forecast of υ_t conditional on $\pi_t - \omega(t)$. This best forecast is equal to the conditional expected value and is given by the right hand side of equation (4.20), where the term preceding $\pi_t - \omega(t)$ is the regression coefficient of υ_t on $\pi_t - \omega(t)$.

Using (3.4) in equation (4.14) with one period lead, i.e., $h_{t+1} = H + u_{t+1} + \varepsilon_{t+1}$,

$$E[h_{t+1} \mid I_{t+1}] = H + \delta^2 u_{t-1} + \delta E[\upsilon_t \mid I_{t+1}]. \tag{4.22}$$

Now substituting equations (4.17), (4.18), (4.20) and (4.22) into (4.16) yields,

$$E[\pi_{t+1} \mid I_{t+1}] \equiv \pi_{t+1}^e = K_1\left(H + \delta^2 u_{t-1} + \delta E[\upsilon_t \mid I_{t+1}]\right) + K_2 \pi_{t+1}^e + K_3 \pi_{t+1}^f + K_4\left(H + \delta^3 u_{t-1} + \delta^2 E[\upsilon_t \mid I_{t+1}]\right),$$

which implies, after rearranging, an expression for public's expectation formation process,

$$\pi_{t+1}^e = \frac{1}{1-K_2}\left\{(K_1 + K_4)H + K_3 \pi_{t+1}^f + \delta^2 (K_1 + \delta K_4) u_{t-1} + \delta\theta[\pi_t - \omega(t)]\right\} \tag{4.23}$$

where, $$\theta \equiv \frac{(K_1 + \delta K_4)^2 \sigma_\upsilon^2}{(K_1 + \delta K_4)^2 \sigma_\upsilon^2 + K_1^2 \sigma_\delta^2}. \tag{4.24}$$

Equation (4.23) implies that a unit increase in π_t increases inflation expectations in the following period by,

$$\frac{\partial \pi_{t+1}^e}{\partial \pi_t} = \frac{\delta\theta}{1-K_2} \tag{4.25}$$

Differentiating policy objective function with respect to π_0, using (4.25) and the fact that $\partial \pi_{t+i}^e / \partial \pi_t = 0$ for $i \geq 2$, the optimal inflation rate in the semi reduced form can be derived:

$$\pi_0 = \frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} h_0 + \frac{\alpha^2(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} \pi_0^e + \frac{d}{[(1-d)(\lambda+\alpha^2)+d]} \pi_0^f$$
$$- \frac{\alpha\beta\delta^2(1-d)}{1-K_2} \theta\left[E_{G,0} h_1 - \alpha E_{G,0}\left(\pi_1 - \pi_1^e\right)\right] \tag{4.26}$$

Because the structure of policymaker's decision problem is same in each period as in the period 0, the decision strategy for any period is given by:

$$\pi_t = \frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} h_t + \frac{\alpha^2(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} \pi_t^e + \frac{d}{[(1-d)(\lambda+\alpha^2)+d]} \pi_t^f$$
$$- \frac{\alpha\beta\delta^2(1-d)}{1-K_2} \theta\left[E_{G,t} h_{t+1} - \alpha E_{G,t}\left(\pi_{t+1} - \pi_{t+1}^e\right)\right] \tag{4.27}$$

The coefficients of equation (4.27) give the solutions to the undetermined coefficients in equation (4.15) such that,

$$K_1 = \frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]}, \tag{4.29}$$

$$K_2 = \frac{\alpha^2(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]}, \tag{4.30}$$

$$K_3 = \frac{d}{\left[(1-d)(\lambda+\alpha^2)+d\right]}, \tag{4.31}$$

$$K_4 = -\frac{\alpha\beta\delta^2(1-d)}{1-K_2}\left(\frac{(K_1+\delta K_4)^2\sigma_\upsilon^2}{(K_1+\delta K_4)^2\sigma_\upsilon^2 + K_1^2\sigma_\delta^2}\right),$$

$$= -\frac{\alpha\beta\delta^2(1-d)\left[(1-d)(\lambda+\alpha^2)+d\right]}{(1-d)\lambda+d}\frac{\left[\left[(1-d)(\lambda+\alpha^2)+d\right]+\delta K_4\right]^2\sigma_\upsilon^2}{\left[(1-d)(\lambda+\alpha^2)+d++\delta K_4\right]^2\sigma_\upsilon^2+\left[(1-d)(\lambda+\alpha^2)+d\right]^2\sigma_\delta^2},$$

$$\equiv \Omega(K_4),\ ^5 \tag{4.32}$$

$$K_5 = -\alpha K_4. \tag{4.33}$$

Using these results and also using the fact that $E_{G,t}h_{t+1} = H + \delta u_t$, the optimal inflation rate follows,

$$\pi_t = \frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]}\left(h_t + \alpha\pi_t^e + \frac{d}{\alpha(1-d)}\pi_t^f\right) - |K_4|\left[H + \delta u_t - \alpha E_{G,t}\left(\pi_{t+1} - \pi_{t+1}^e\right)\right] \tag{4.34}$$

If inflation rate of the foreign country is assumed to be zero, the first term in parentheses is reduced to $(h_t + \alpha\pi_t^e)$, which implies the difference between desired and actual employment levels when inflation rate in home country is set equal to zero in period *t*. The second term in the right hand side of equation (4.34) implies the same difference as expected by the policymaker in period *t*, for the following period. The implications of this equation are straightforward. A positive deviation of actual employment from the desired level in the current period would result in higher optimal inflation rate. On the contrary, if policymaker expects a positive future deviation of actual employment, optimal inflation rate would be lower. As described by Cukierman, the behaviour of these two terms may well be explained proportionately to the marginal cost of low employment. An expansionary policy in the current period would increase next period's inflation expectations which results in lower employment, i.e., higher marginal cost of low employment in the next period. Because policymaker dislikes reduction in next period's employment, it may attempt to reduce higher inflation expectations by lowering current inflation rate. Thus, the inflation bias of the policymaker in the current period would be partly off set due to perceived reductions in employment in the next period.

---

[5] Following Cukierman (1992), it can be shown that K_4 has always a non-positive solution. (p.281).

However, in the first place, the impact of current deviations of employment on the optimal inflation rate depends on how much constrained the nominal exchange rate is. Equation (4.34) implies that when the exchange rate is more rigid (i.e., a higher *d*) the coefficient of the first term becomes smaller constraining the policymaker's temptation to pursue an activist policy. On the other hand, a more flexible exchange rate implies a strong incentive of policymaker to respond to current marginal cost of low employment. Thus, the open economy version of Cukierman model clearly implies an asymmetric response of policymaker to varying marginal cost of low employment under different exchange rate regimes.

4.2.2 Persistence in Inflation Expectations

An important advantage of the assumption of information asymmetry is that it helps to model public's expectation formation process more realistically. In real world, public may not be informed about the persistent and transitory components of shocks, at the same time as policymaker. Therefore, as shown in the following result, their expectations formation process includes transitory shocks as well.

Using equations (4.19) and (4.21) to form:

$$\pi_t - g(t) = (K_1 + \delta K_4)\upsilon_t + K_1\varepsilon_t \,,$$

as shown in Appendix A, using the solutions in equations (4.29), (4.30), and (4.23) with the above expression and taking one period lag yields the current periods inflation expectations:

$$\pi_t^e = \frac{(1-d)(\lambda+\alpha^2)+d}{(1-d)\lambda+d}\left[\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]}+K_4\right)H + K_3\pi_t^f\right]$$
$$+\frac{[(1-d)(\lambda+\alpha^2)+d]}{(1-d)\lambda+d}\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]}+\delta K_4\right)$$
$$\cdot\left[\delta^2 u_{t-2} + \delta\theta\left(\upsilon_{t-1} + \frac{\alpha(1-d)}{\alpha(1-d)+\delta[(1-d)(\lambda+\alpha^2)+d]K_4}\varepsilon_{t-1}\right)\right] \qquad (4.35)$$

Equation (4.35) explains inflation persistence implied in the model under asymmetric information. Because public does not possess as much information as policymaker, they are unable to fully disentangle *previous* period innovation to persistent part of employment (υ_{t-1}), from the transitory part of employment in that period, (ε_{t-1}). Thus, period *t* expectations are affected by past transitory shocks, which results in persistence in inflation expectations. On the contrary, policymaker obtains up-to-date information on the decomposition of permanent and transitory shocks, so it does not directly react to transitory shocks. However, policymaker partly accommodates current inflation expectations as implied by α in equation (4.34). Because public expectations are affected by past transitory shocks, the current inflation is also then affected by transitory shocks. Thus, asymmetric information transforms transitory shocks to natural employment into persistent movements in actual inflation.

However, equation (4.35) is not a reduced form solution to the policymaker's optimization problem. Therefore, as shown in Appendix B, a reduced form expression is derived for optimal inflation rate chosen by the policymaker under asymmetric information. In the same token of inflation persistence implied in equation (4.35), the reduced form optimal inflation implies the inflation persistence due to sluggishness in inflation expectations in terms of various components of the natural rate employment. Importantly, the role played by the parameter relating to constraint of the nominal exchange rate, and the sensitivity to the foreign inflation rate explicitly modeled.

$$
\begin{aligned}
\pi_t =\; & \frac{\left(\alpha(1-d)+\left[(1-d)\left(\lambda+\alpha^2\right)+d\right]K_4\right)}{(1-d)\lambda+d} H + \left(\frac{d}{(1-d)\lambda+d}\right)\pi_t^f \\
& + \frac{\left(\alpha(1-d)+\left[(1-d)\left(\lambda+\alpha^2\right)+d\right]\delta K_4\right)}{(1-d)\lambda+d}\delta^2 u_{t-2} \\
& + \left(\frac{(1-d)\left(\lambda+\alpha^2\theta\right)+d}{(1-d)\lambda+d}\right)\left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^2\right)+d\right]}+\delta K_4\right)\delta\upsilon_{t-1} \\
& + (1-\alpha\delta(1-\theta)K_4)\left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^2\right)+d\right]}+\delta K_4\right)\upsilon_t + \frac{(1+K_4\alpha\delta\theta)}{\left[(1-d)\left(\lambda+\alpha^2\right)+d\right]}\alpha(1-d)\varepsilon_t \\
& + \left(\frac{\alpha^3(1-d)^2}{((1-d)\lambda+d)\left[(1-d)\left(\lambda+\alpha^2\right)+d\right]}\right)\delta\theta\varepsilon_{t-1} \qquad (4.36)
\end{aligned}
$$

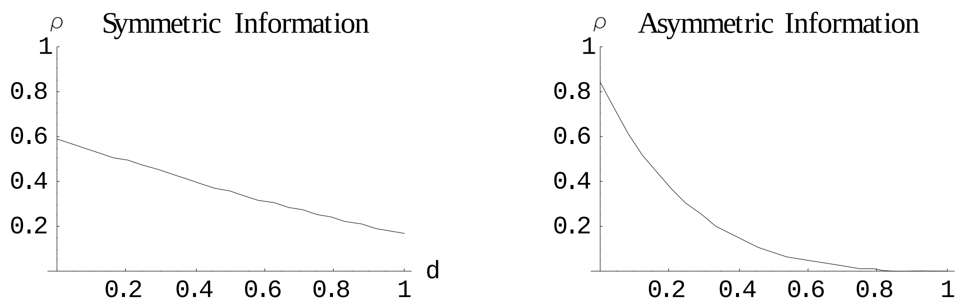
Equation (4.36) is a straightforward extension of Cukierman's reduced form solution for closed economy model. In this result, the impact of exchange rate flexibility and the foreign country's inflation rate provide more insight into policymaker's optimization solution. More importantly, equation (4.36) can explain inflation persistence given the assumption of asymmetric information. The key implication of inflation persistence derives from the fact that optimal inflation rate in current period responds to past transitory shocks to the natural rate of employment, despite they do affect the natural rate. Because our assumption allows public to obtain information about the components of shocks to natural rate after two periods, they do not observe persistence and transitory components of previous period's shocks (υ_{t-1}), in the current period. Therefore, they take π_{t-1} alternatively, into expectations formation process. However, π_{t-1} are also affected by transitory shocks ε_{t-1} because of lack of information, and therefore inflation expectations always carry some element of transitory shocks to natural rate. Since, policymaker in each period responds to inflation expectations, current inflation responds to past transitory shocks.

In order to explain the behaviour of inflation persistence under asymmetric information, an expression is derived for correlation between current and past inflation using the optimal inflation rate in equation (4.36). As shown in Appendix C, the inflation persistence coefficient takes the following form:

$$\rho^{AI}_{(\pi_t,\pi_{t-1})} = \left\{ \frac{\left[(1-d)(\alpha^2+\lambda)+d\right]^2}{\left[(1-d)\lambda+d\right]} \left[(1-d)^3\alpha^4\delta\theta(1+\alpha\delta\theta K_4)\right]\sigma_\varepsilon^2 \right.$$
$$\left. + \frac{\left[(1-d)(\alpha^2\theta+\lambda)+d\right]^2}{\left[(1-d)\lambda+d\right]} \delta(1+\alpha\delta K_4(1-\theta)) \left[\frac{(1-d)\alpha}{\left[(1-d)(\alpha^2+\lambda)+d\right]^2} + \delta K_4\right]^2 \sigma_\nu^2 \right\} \Big/$$
$$\left\{ \left(\frac{(1-d)\alpha\delta\theta}{\left[(1-d)(\alpha^2+\lambda)+d\right]}\right)^2 \left[(1+\alpha K_4)^2 + \left(\frac{(1-d)\alpha^2}{\left[(1-d)\lambda+d\right]}\right)^2\right]\sigma_\varepsilon^2 \right.$$
$$+ \frac{\delta^4}{\left[(1-d)\lambda+d\right]^2}\left[(1-d)\alpha + \left[(1-d)(\alpha^2+\lambda)+d\right]\delta K_4\right]^2 \sigma_u^2$$
$$\left. + \left((1-\alpha\delta K_4(1-\theta))^2 + \left(\frac{\delta^2\left[(1-d)(\alpha^2\theta+\lambda)+d\right]^2}{\left[(1-d)\lambda+d\right]^2}\right)\left[\frac{(1-d)\alpha}{\left[(1-d)(\alpha^2+\lambda)+d\right]^2} + \delta K_4\right]^2 \right)\sigma_\nu^2 \right\} \tag{4.37}$$

Equation (4.37) implies that the inflation persistence coefficient under asymmetric information responds to variance of various components of the natural level of employment. Further, as implied in equation (4.11), persistence is introduced through nonzero values of δ, and it also depends on the parameters α, λ, d, and θ which relates to the *speed of learning*. As implied in equation (4.36), where current inflation also responds to previous transitory shocks, asymmetric information may result in more persistence in the inflation process. As shown in Figure 6, that may seem to be the case for lower variance values of the error term of the persistent component of shocks. Figure 6 compares inflation persistence under symmetric and asymmetric information, for $\delta = 0.25$ and $\rho = 0.5$. The initial level of persistence is lower under symmetric information (about 0.6) and it is higher under asymmetric information (about 0.8). However, this result is true only for lower variance (e.g., $\sigma_\nu^2 = 0.01$) of the error term in the persistence component. Further, the path of persistence is significantly different under two cases, as $d \to 1$, where persistence tends to be $\rho^{SI}_{(\pi_t,\pi_{t-1})} = \delta \Big/ \left(1+\frac{\sigma_\varepsilon^2}{\sigma_u^2}\right)$ under symmetric case, and it approaches zero under asymmetric information.

Figure 6: Inflation persistence under Symmetric and Asymmetric Information



Moreover, the response of inflation persistence under asymmetric information differs from symmetric information on various counts.

Result 4: *Inflation persistence increases only for up to a certain levels of autocorrelation of shocks (e.g.,* $\delta < 0.50$ *), and beyond that it starts declining, for given values of variance of shocks to employment.*

Figure 7 shows the path of inflation persistence under different levels of autocorrelation of shocks, given variance of all components to be equal to 0.05. The initial level of persistence is increasing as $\delta \to 0.50$, and it tends to decrease afterwards as $\delta \to 1$. This response is much clearer in Figure 8, where inflation persistence coefficient has upward trend as $\delta \to 0.50$, and starts declining. Further, similar to the symmetric information case, a similar response can be observed for a higher variance σ_ν^2 of persistent component, which leads to less persistence, having the relation between ρ and δ in tact, as shown in Figure 7.

Figure 7: Asymmetric Response of Inflation persistence for different values of degree of autocorrelation of supply shocks

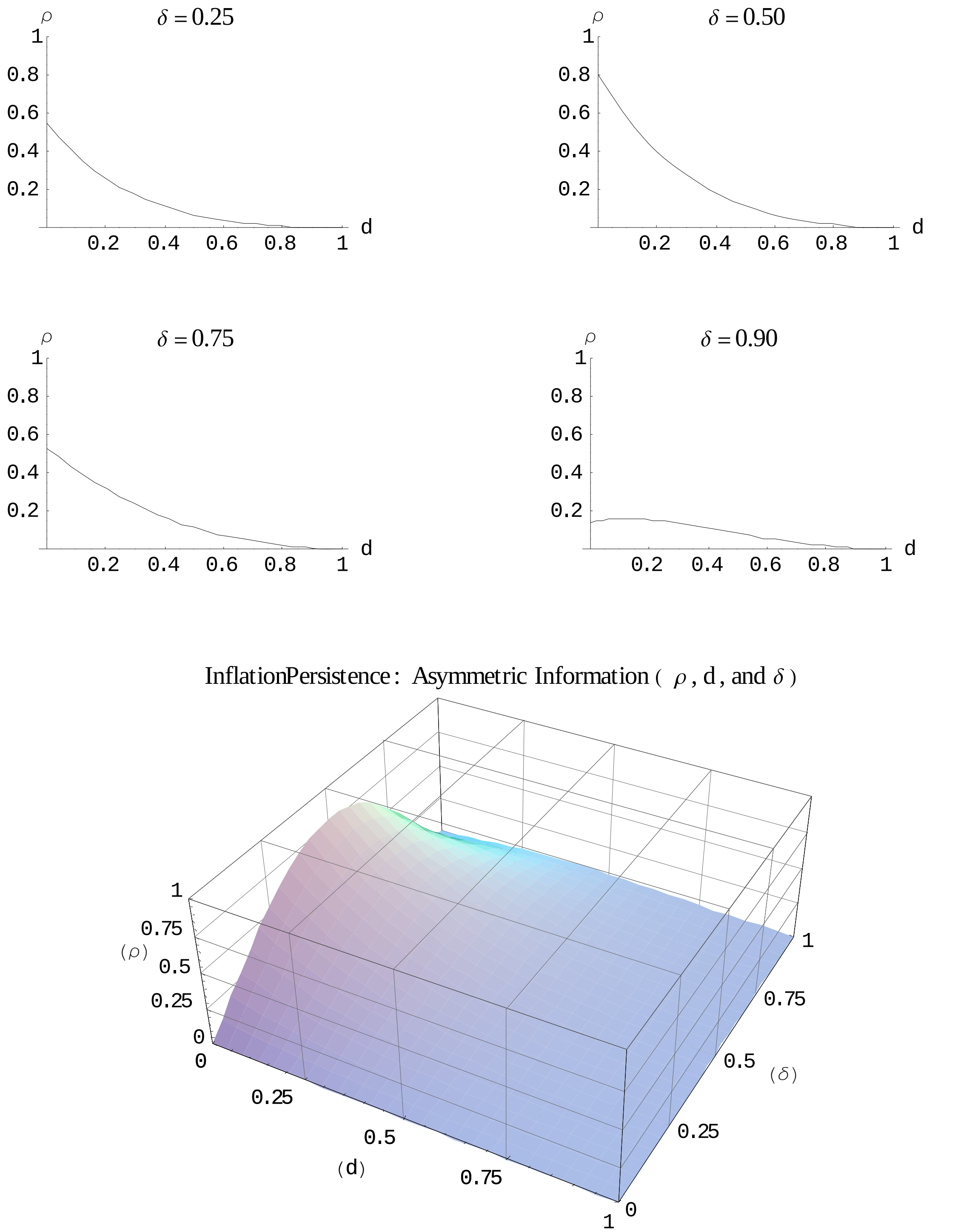
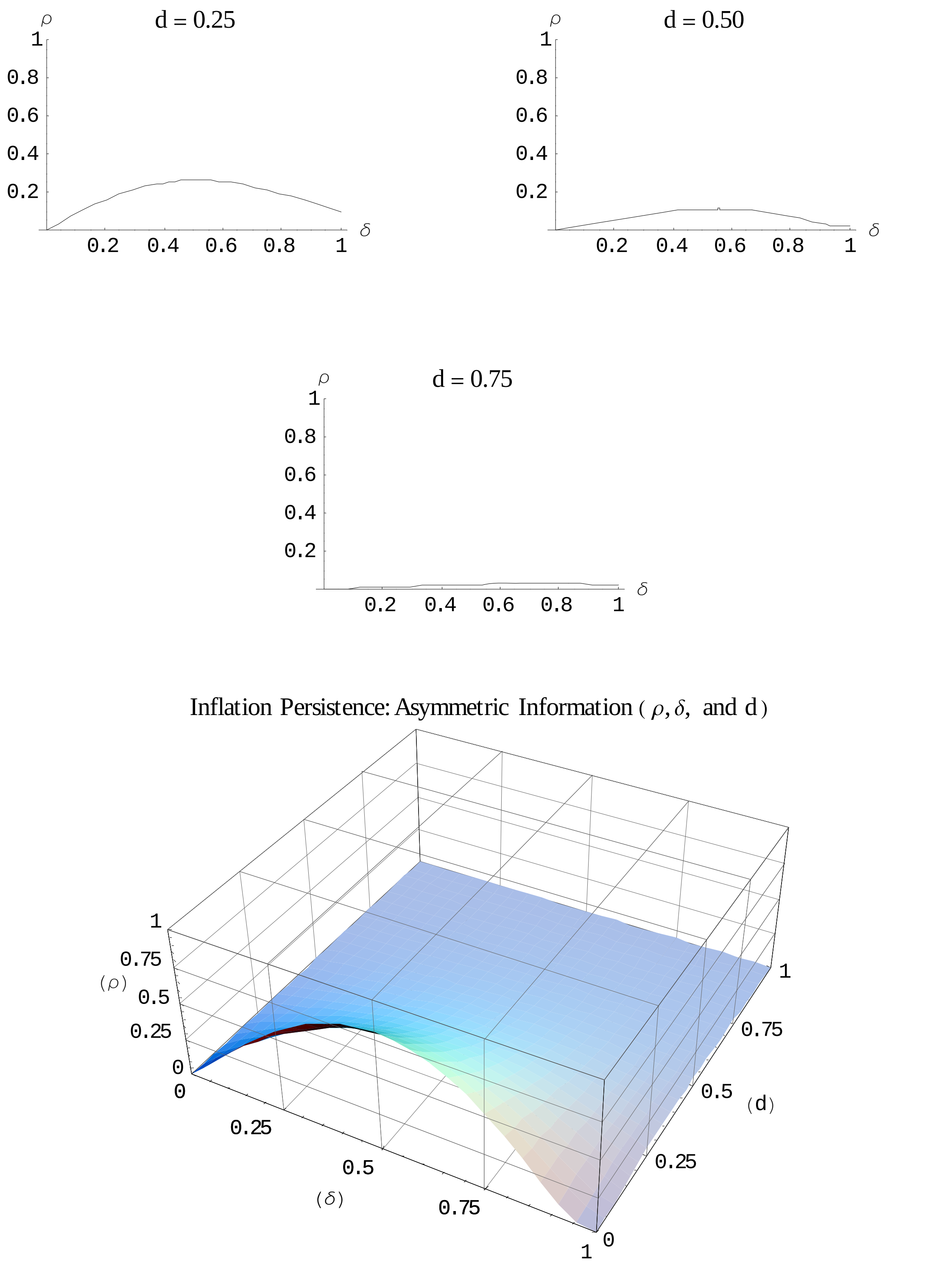


Figure 8: Inflation persistence and degree of autocorrelation of supply shocks



4.2.3 Comparative Statics under Asymmetric Information

The Figures from 9 and 10 show the behaviour of inflation persistence to a change in the degree of exchange rate flexibility and degree of autocorrelation.

Result 5: *The response of inflation persistence to a change in the degree of exchange rate flexibility is negative, and more flexibility results in more persistence, as expected. However, for highly autocorrelated shocks, the impact of change in d would be minimal.*

Figure 9 shows the response of inflation persistence to a change in d , under different levels of autocorrelation of shocks. As $d \to 1$, persistence coefficient declines through out, and it is highly observed for lower values of δ. For highly autocorrelated shocks, a change in *d* would have only minimal impact. However, results change remarkably for an increase in the variance of persistent component. For example, for higher variance of σ_{υ}^{2} , the path of the persistence component becomes highly volatile. All the graphs in Figure 8 are based on $\sigma_{\upsilon}^{2} = 0.01$.

Result 6: *The initial response of inflation persistence to an increase in the degree of autocorrelation of shocks is positive. However, the path of persistence becomes negative for higher autocorrelated shocks (e.g., $\delta > 0.40$).*

As shown in Figure 10, the initial positive impact due to an increase in autocorrelation dies out as $\delta \to 1$. During the process, more autocorrelated shocks results in lowering the persistence. Also the impact of a change in the degree of autocorrelation lessons for more constraint exchange rates.

Figure 9: Inflation persistence response to a change in the degree of exchange rate flexibility

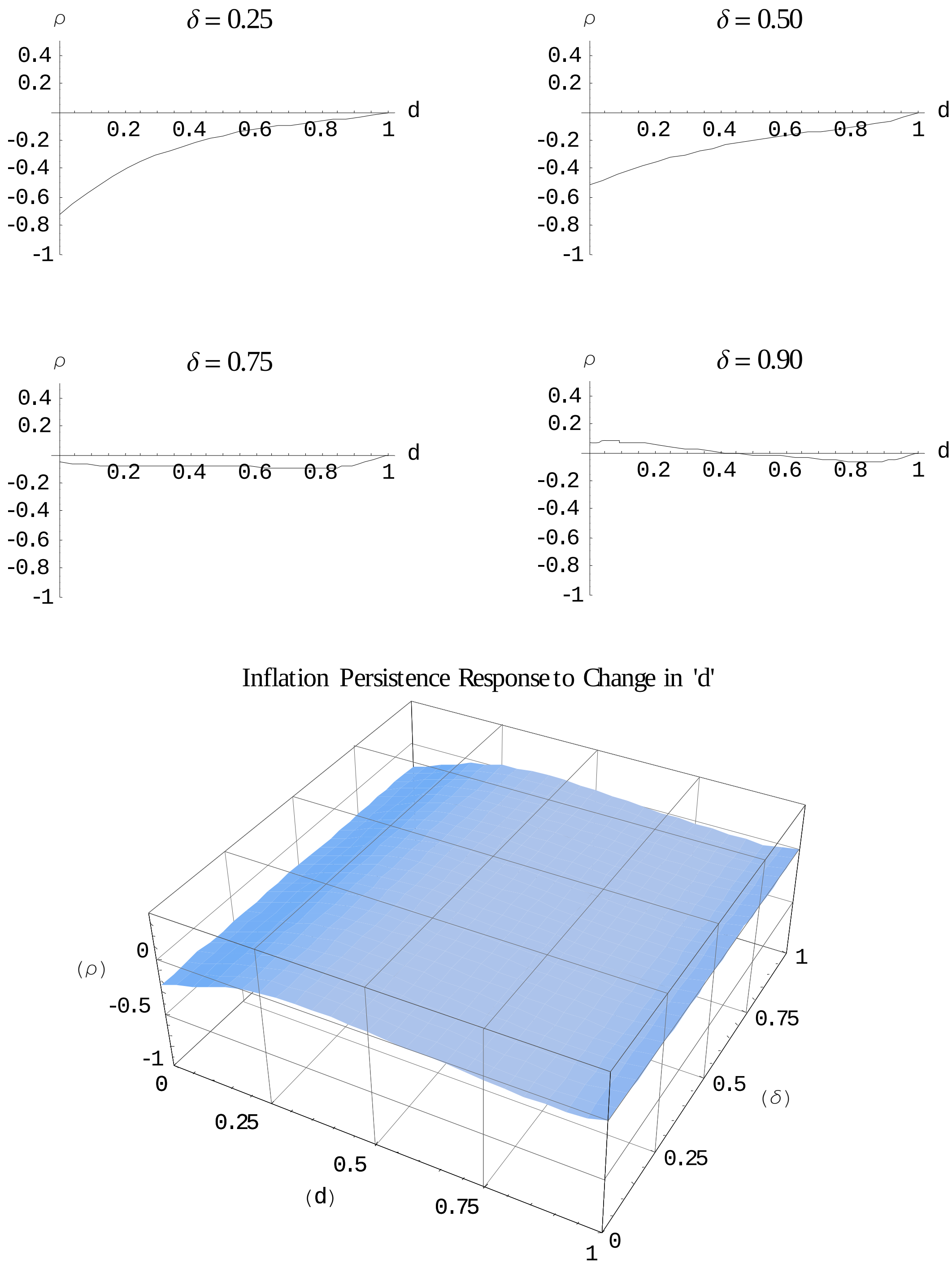
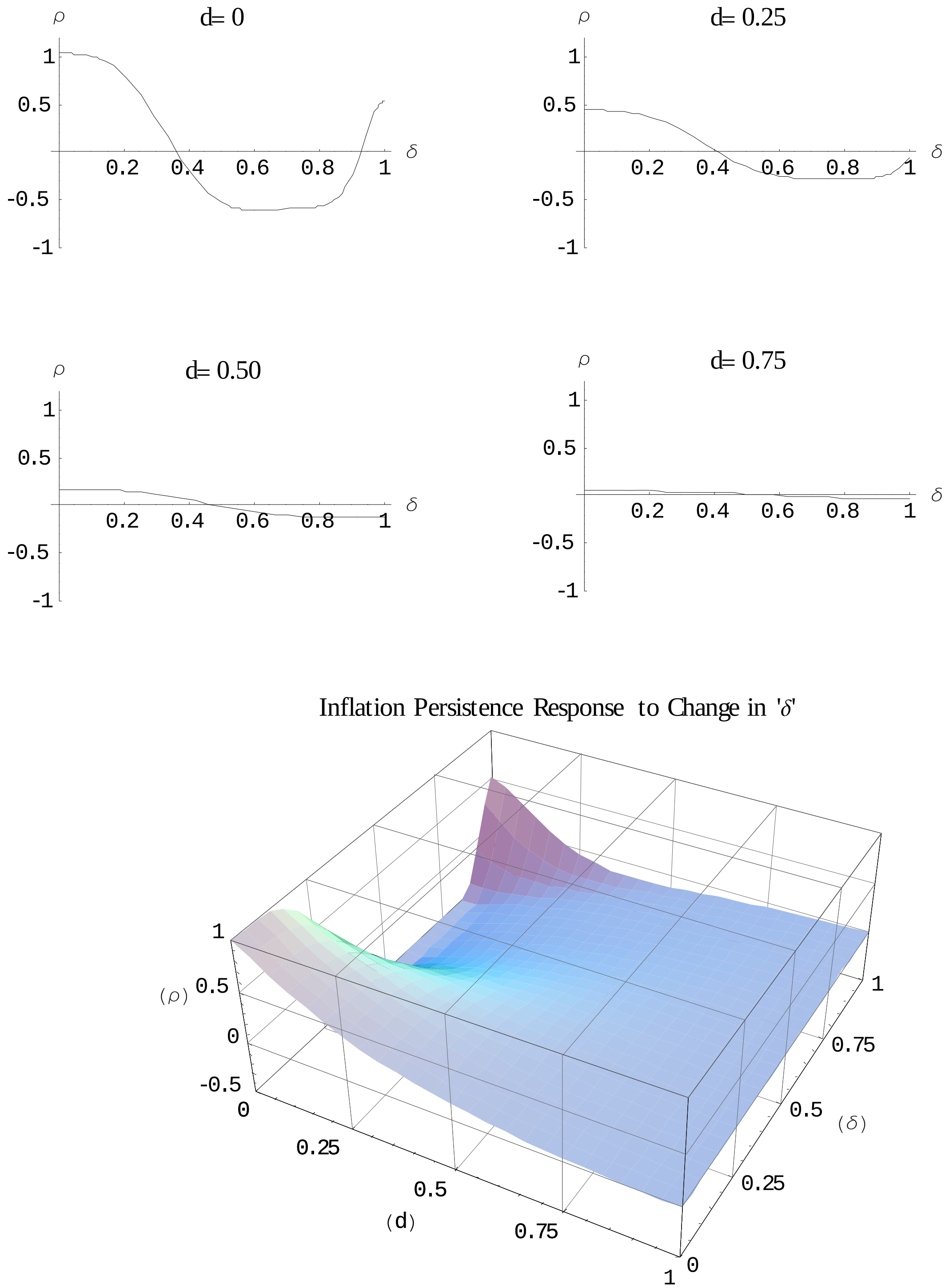


Figure 10: Inflation persistence response to a change in the degree of autocorrelation of natural rate shock



5. Empirical Evidence

This section tests empirically the hypothesis that inflation persistence varies with the exchange rate regimes. To allow for time variation in exchange rate regimes, we use historical UK and US data on inflation, covering, four distinct exchange rate regime periods, i.e., the Classical Gold Standard, the interwar Gold Standard, the Bretton Woods, and the recent period of floating. Thus, our data sample starts from 1850 for UK, and from 1870 for US (see Data Appendix for the sources and definitions of inflation series). We employ a number of standard and unknown-break-point tests of structural change in the context of a univariate inflation model. The standard tests include recursive plots of persistence parameter based on full-sample estimates, and sub-sample estimates of mean inflation and persistence parameter based on *de facto* exchange rate regime classifications. Similar approach is found in the articles of Alogoskoufis and Smith (1991), Benati (2006, 2008), among others. Owing to several drawbacks of the standard tests, as discussed later, we also use state-of-the-art techniques to test for structural breaks as proposed by Qu and Perron(2007) to identify breaks in mean inflation and persistence over time. According to our understanding, this paper seems to be the first attempt in the literature to be using newest structural change tests, on a historical inflation dataset.

Figure 11 depicts the inflation series of UK and US across monetary regimes. As shown, the behaviour of the inflation process seems to have changed identically in both countries over time. In the Classical Gold Standard period inflation tends to be stable and lower, followed by a highly volatile inflation rates during interwar years. Again, during the Bretton Woods period inflation rates become stable and lower. After the collapse of the Bretton Woods system inflation rates increase dramatically and then start declining with the stabilization polices implemented by both countries, since early 1980s. Further, Figure 12 shows a dramatic upward shift in the inflation process during 1914 and 1916 and a moderate shift mid 1970s.

5.1 Methodology

In order to identify how these changes reflect in the mean of the inflation and in the persistence parameter, and also whether these changes correspond to changes in the exchange rate regimes, we carry out estimates based on sub-samples, as well as the full-sample with regime dummies. We also account for the effects of World Wars. We use four alternative inflation series for UK, namely, GDP Deflator inflation, Personal Consumption Expenditure (PCE) Deflator inflation, Composite Price Index inflation and Cost of Living Index inflation. For US, we use three inflation series namely, a) GNP deflator inflation, b) CPI inflation, and c) PCE deflator inflation. All price indices are found to be non-stationary in levels, and, therefore, they are made stationary by taking first difference. Each inflation series, thus obtained, is specified as an autoregressive process, in which the order of lag is selected by the *Schwarz Information Criterion* (SIC). In most cases the lag order selected is one, except for few occasions when sub-sample estimates are carried out.

Thus, we specify the inflation process as follows:

$$\pi_t = \alpha + \beta\pi_{t-1} + \varepsilon_t \text{,} \qquad (5.1)$$

where π_t is actual inflation, ε_t is serially uncorrelated error term. α and β are estimated via OLS. Thus, the parameter β refers to inflation persistence, and mean of the inflation process is determined by $\alpha/(1-\beta)$.

For models with more than one lag, persistence coefficient is estimated using the 'sum of the autoregressive coefficients' procedure as proposed by Andrew and Chen (1994). Therefore, the AR specification with more than one lag is a re-parameterization of the above autoregressive model:

$$\pi_t = \alpha + \rho\pi_{t-1} + \sum_{j=1}^{p-1} \phi_j \Delta\pi_{t-1} + \varepsilon_t, \qquad (5.2)$$

where $\rho = \sum_{j=1}^{p} \beta_j$, $\phi_j = -\sum_{i=1+j}^{p} \beta_i$.

Now, inflation persistence is given by the estimate of ρ, and mean inflation is given by $\alpha/(1-\rho)$.

Figure 11: Changes in the Inflation Process across Monetary Regimes

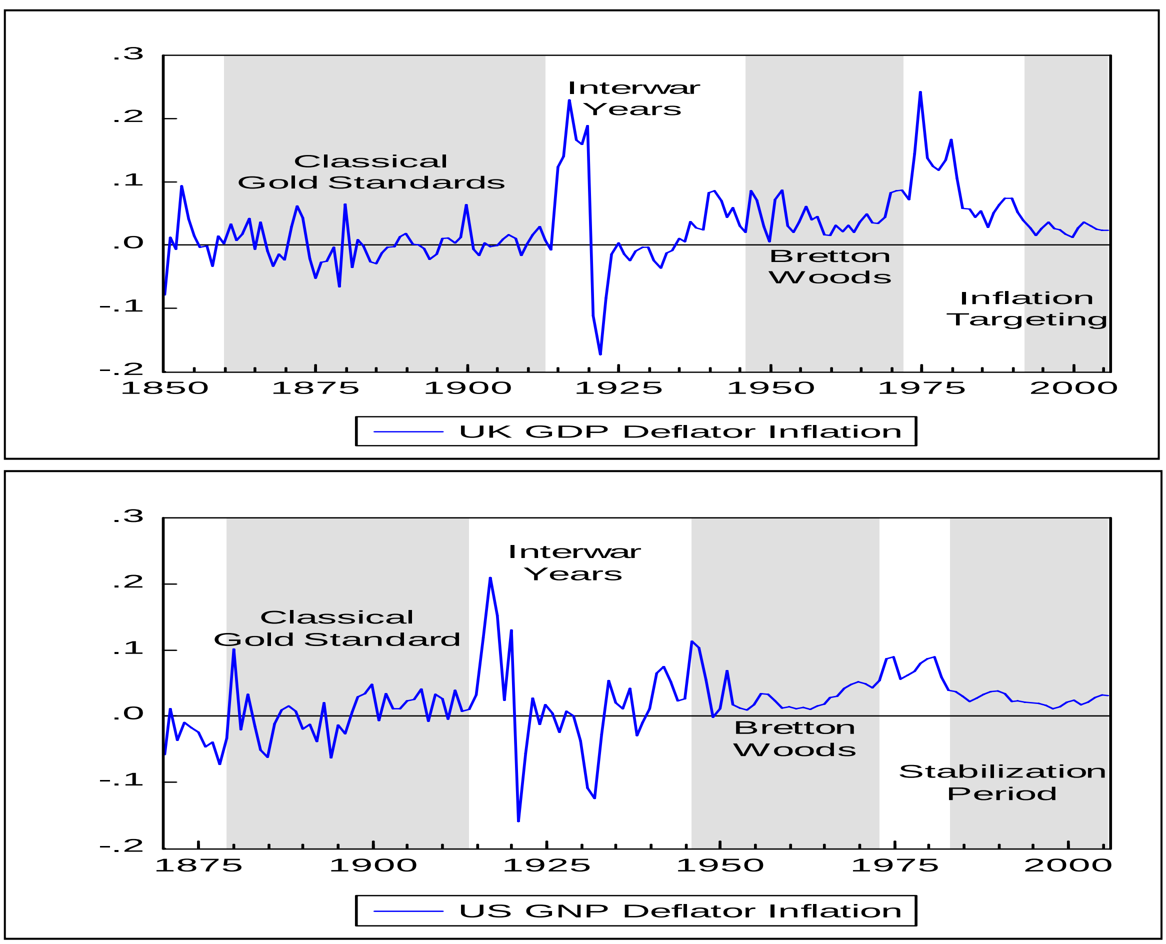
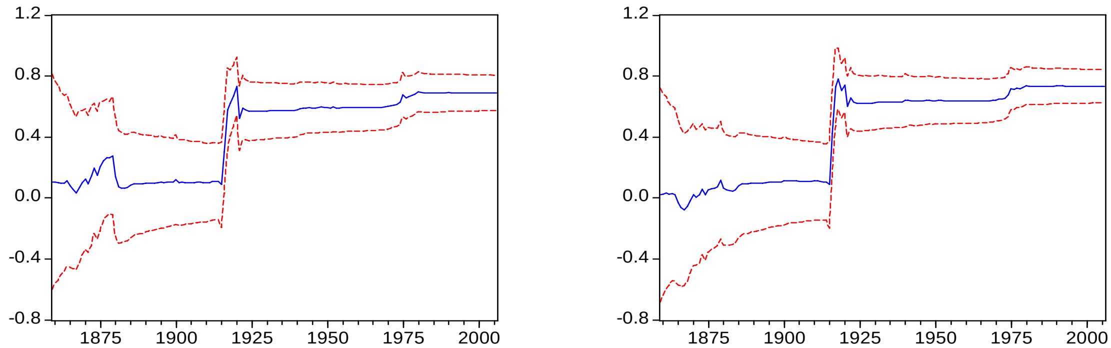
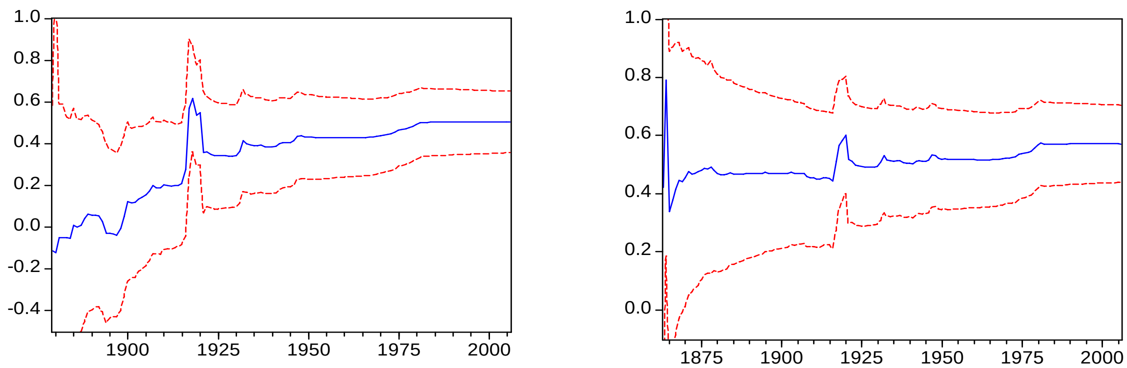


Figure 12(A): Recursive Estimates of lagged inflation coefficient: United Kingdom



(a) GDP Deflator Inflation *(b) PCE Deflator Inflation*

Figure 12(B): Recursive Estimates of lagged inflation coefficient: United States



(a) GNP Deflator Inflation *(b) CPI Inflation*

(a) Sub-sample estimates

Our sample is divided into following sub-samples. For UK, covering five main regime changes namely, a) *Classical Gold Standard* (1850-1913), b) *Interwar Gold Standard* (1923-1939), c) *Bretton Woods System* (1946-1972), d) *Flexible Exchange Rate regime* (1972-1992), and finally, e) *Inflation Targeting regime* (from 1992 onwards). For US, we initially identified six regimes namely, *Greenback Period* (1861-1878), *Classical Gold Standard* (1879-1914), *Interwar Period* (1919-1941), *Bretton Woods System* (1946-1973), *Grater Inflation Episode* (1972-1982), and *Post-stabilization* (1983-2006). However, estimates relating to the *Post-stabilization* period tendered insignificant, and therefore, we combine the last two periods as *Flexible Exchange Rate regime* (1972-2006).

(b) Full-sample estimates with regime effects

In order to account for regime effects and the possible impact of world wars explicitly, we estimate the whole sample data with dummies relating to monetary regimes and the World War I and II. Regime dummies are defined as taking 1 for the years during which the regime is in effect, and 0 elsewhere, so as the war dummies.

Each regime dummy is defined as an intercept dummy as well as an interaction dummy i.e. a product of the dummy and lagged inflation term. War dummies are defined as intercept dummies. Thus, the following AR model is estimated via OLS;

$$\begin{aligned}\pi_t = {} & \alpha + \rho\pi_{t-1} + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_4 + \\ & \beta_6 (D_1 * \pi_{t-1}) + \beta_7 (D_2 * \pi_{t-1}) + \beta_8 (D_3 * \pi_{t-1}) + \beta_9 (D_4 * \pi_{t-1}) + \beta_{10} (D_5 * \pi_{t-1}) + \\ & \beta_{11} WWI + \beta_{12} WWII + \varepsilon_t\end{aligned} \quad (5.3)$$

where π_t is inflation, α is a constant, ρ is the estimate of persistence coefficient, *D*s refer to regimes defined above, β s are parameters to be estimated and ε_t is serially uncorrelated error term.

The definitions of war dummies are slightly different across UK and US. For UK, World War I dummy takes 1 during 1914-1918 and 0 elsewhere, and World War II dummy takes 1 during 1940-1945 and 0 elsewhere. Further, in order to examine the sensitivity of possible changes in timing of regimes, two dummies are re-defined viz., Bretton Woods dummy as from 1957 to1968 (which is considered to be the Hayday of Bretton Woods), and World War I dummy as from 1914 to 1922 (however, the estimates do not affect the previous results and hence not reported). For US, World War I dummy is set at 1 during 1917-1919 and 0 elsewhere, and World War II dummy takes 1 during 1942-1945 and 0 elsewhere. Further, an additional dummy is included for US estimates, referring to Vietnam War (1965-75).

5.2 Estimates of Mean Inflation, Inflation Persistence across Exchange Rate Regimes

The results based on sub-samples and full-sample estimates are reported in Table 1 and Table 2, respectively. We first describe the behaviour of mean inflation across monetary regimes in UK and US. Then, the similar analysis is extended to look at the behaviour of inflation persistence coefficient across monetary regimes.

(a)Mean Inflation

There is enough evidence to suggest that mean of inflation is time varying, and variations are partly attributable to changes in exchange rate regimes. In UK, mean inflation tends to be substantially low, during the Classical and Interwar Gold Standards (estimates ranging from 0.001 to 0.003), reconfirming the existing literature on white-noise inflation process during the Gold Standard era. The change in the mean inflation with the shift from Classical Gold Standard to Interwar Gold Standard is subtle. In US, the Greenback period is associated with lower negative mean inflation, as implied in all inflation series considered (ranging from -0.004 to -0.007). The shift from Greenback to Classical Gold Standard results in lower positive mean inflation, and it again marks negative mean inflation during the interwar period. However, the estimates of mean inflation during these two regimes in both UK and US are in very low levels and rendered statistically insignificant at conventional levels. On the contrary, the mean inflation estimates in Bretton Woods are comparatively higher in both UK and US, which are marked at 0.04 and 0.03, respectively. Further, Floating regime (prior to inflation targeting) marks the highest mean inflation in UK which is around 0.08, and for US, it is around 0.04. However, UK inflation targeting regime brings back its mean inflation rate to lower levels , which hovering around 0.025.

Overall, one can see a clear shift in mean inflation during the transition from Bretton Woods to Floating regime in UK, though such evidence is not quite apparent in US. Further, there is some evidence to suggest that the mean inflation does change with the shift from Classical Gold Standard to Interwar Gold Standard, with less precision though. Further, there is clear evidence in UK that adoption of inflation targeting results in grater reduction in mean inflation.

(b) Inflation Persistence

Similarly, estimates of inflation persistence show significant changes across exchange rate regimes. In UK, persistence parameter estimate differs significantly between the Classical and Interwar Gold Standard periods, though countering the fact that fixed exchange rate regimes are associated with lower degree of inflation persistence. One reason might be lack of public confidence on Interwar Gold Standard as a credible monetary regime. On the contrary, in US, the shift from Greenback to Interwar period marks a significant downward shift of persistence estimates. Thus, compared with the estimates of mean inflation between these regimes, persistence coefficient shows some significant changes.

Further, comparing Bretton Woods and Floating regime, UK inflation persistence shows a marked shift from lower levels (around 0.40) to higher levels (around 0.70) providing supportive evidence to the hypothesis that fixed exchange rate regimes are associated with lower inflation persistence, and flexible regimes produce higher levels of persistence. Similarly, in US, Bretton Woods period marks the persistence coefficient around 0.45 percent, and it jumps to higher levels of 0.80 in the Floating regime. Thus, inflation persistence in the Flexible regime in US marks the highest in all inflation series. However, in UK, the picture is slightly difference because of the inflation targeting regime adopted since 1992, in that persistence estimates fall again back to lower levels ranging between 0.30 and 0.40.

Overall, both mean inflation and persistence estimates suggest that changes in exchange rate regimes do have an impact on the inflation process, while new developments occurring within a regime may also lead to changes in both mean and persistence of the inflation process.

However, there are some caveats associated with these estimates due to some methodical issues. We observe that the estimates are sensitive to the fact that whether they are based on sub-samples or full sample period with regime dummies. Further, apart from the effects of regime changes on inflation persistence, there are several other factors, such as break-out of wars, that may affect mean inflation and persistence estimates. We find significant coefficient estimates for war dummies. Similarly, Burdekin and Siklos (1999) find significant evidence on the impact of oil price shocks and institutional changes, such as central bank reforms on inflation persistence estimates. Further, one crucial factor is how we define regimes. The results reported, so far, are based on pre-imposed regime breakpoints. This is one of the major criticisms against standard techniques championed by Alogoskoufis and Smith (1991). Another important issue which attracts greater attention in recent empirical literature on measuring inflation persistence is the treatment of mean inflation. Many studies who attempt to measure *overall* degree of inflation persistence do not allow for possible shifts in the mean of inflation. As described by Perron (1990) failure to take account for such mean breaks could lead to spuriously overestimated degree of inflation persistence. Recently, various studies find evidence of lower inflation persistence once mean shifts are allowed for. However, there exists some dispute among researchers about the driving force of mean shifts. Bilke (2004) provides strong evidence in support of the proposition that mean breaks in inflation are driven by monetary policy itself. However, researchers believe that if monetary policy drives break in means, it should reflect in all the sectors in the economy, which is not supported in most studies (Angeloni *et al*., 2004). In the next section we address this issue.

5.3 Testing Structural Changes at Unknown Dates

There are several methods available for testing multiple structural changes. Early work relates to breakpoint tests at known break dates (see Chow(1960)). Because of obvious limitations on the assumption of known break dates, researchers subsequently attempted to describe procedure to test and estimate for unknown breaks. For example Andrews (1993), Andrews and Ploberger (1994), Bai and Perron (1998, 2003), Hansen (2001), Qu and Perron (2007). Among them, Bai and Perron approach has been a benchmark due to its less restrictive assumptions such as allowing for general forms of serial correlation and heteroskedasticity in the errors, and allowing for different distributions for the errors and the regressors across segments. However, as Bai and Perron (1998)'s procedure was originally intended to describe only single break case, there are limitations of this procedure when multiple breaks exist as the test may tend to imply a fewer breaks (Lildholdt and Wetherilt, 2004). Therefore, Qu and Perron (2007) extend the same class of tests to multiple breaks, using multiple regression models. As described by Bataa et al., (2007), Qu and Perron's procedure seems to be appropriate for univariate processes as well.

Therefore, in this section, we attempt to use Qu and Perron(2007) structural stability tests, to examine breaks in the mean and persistence of the inflation process.

The methodology adopted here is two-fold. First, we test for breaks in the mean of inflation. Second, having allowed for breaks in mean of inflation, we test for breaks in persistence.

(a) Unconditional mean breaks

The steady state equilibrium condition implies that actual inflation is equal to the mean of the inflation process:

$$\pi_t = \mu .$$

However, because of shocks, mean inflation can vary over time. Therefore, we test for breaks in the mean inflation:

$$\pi_t = \mu_{t,j} + \varepsilon_t , \tag{5.4}$$

where $\mu_{t,j}$ implies the time varying mean inflation, and *j* indicates the regime. ε_t can be both autocorrelated and heteroskedastic.

(b) Breaks in persistence

Due to shocks, actual inflation varies from the mean inflation. As shocks die out slowly because of nominal rigidities (price stickiness or wage contracting), the adjustment of actual inflation towards mean inflation would be a slower process:

$$\pi_t - \pi_{t-1} = \rho(\mu - \pi_{t-1}) + \varepsilon_t ,$$

where ρ is a positive parameter. A higher ρ implies a faster adjustment and lower persistence. ε_t is serially uncorrelated error term. As it is not clear in this model whether breaks occur in the mean of inflation or in the persistence parameter, we allow for mean breaks prior to identifying breaks in persistence. Therefore, we obtain mean removed inflation series, by subtracting time varying mean inflation from actual inflation series. Similar approach can be found in Ng and Vogelsang (2002), Bataa *et al.*(2007), among others.[6] Thus, the mean removed inflation process takes the following form:

$$\pi'_t = (1-\rho)\pi'_{t-1} + \varepsilon_t , \tag{5.5}$$

where $\pi'_t = \pi_t - \mu_{t,j}$.

We employ Qu and Perron (2007) testing procedure on equations (5.4) and (5.5) to test and estimate breaks in the unconditional mean and persistence parameter in GDP Deflator inflation series in UK and GNP Deflator inflation series in US. However, we come across a technical issue here in accounting for the effects of World Wars on the inflation process. Because, Qu and Perron (2007) procedure does not allow for including dummy regressors (for obvious reason, as there would be one regime whose regressor is identically zero[7]), we refine the initial estimates after testing for breakpoints.

5.4 Results

(a) Breaks in the unconditional mean of inflation

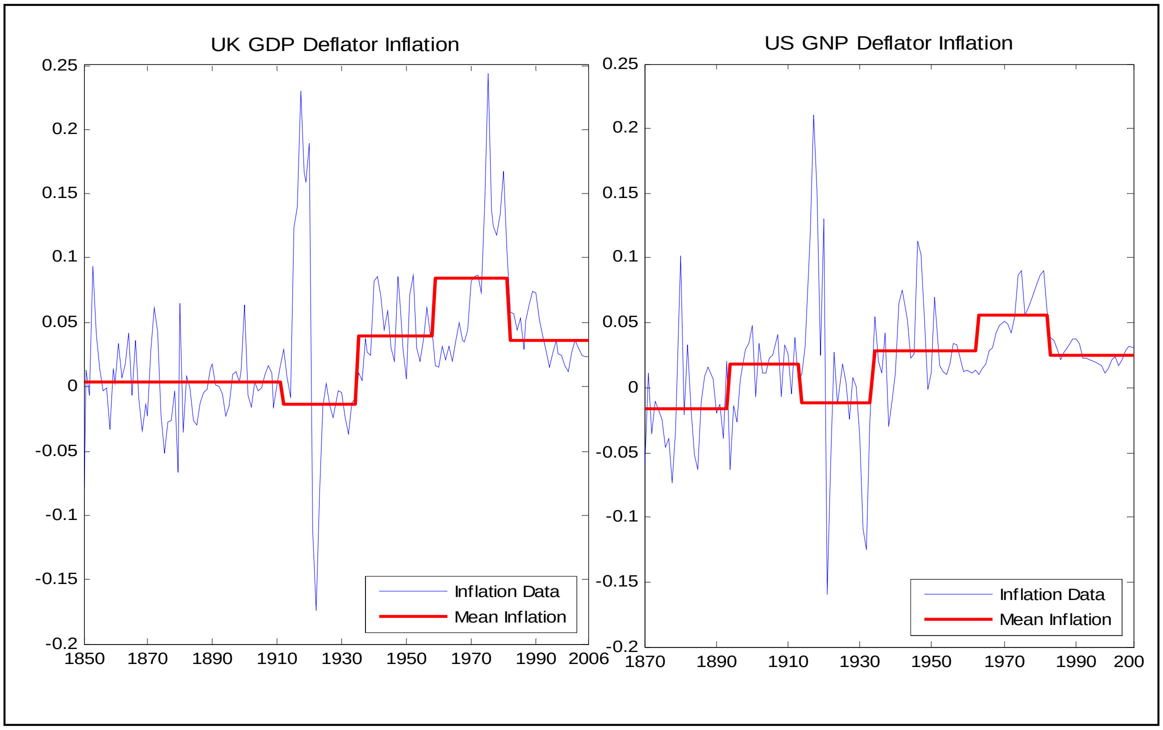
Table 3 reports the breakdates and estimates of mean inflation with 90 percent confidence intervals. Figure 13 shows the shifts in the mean of the inflation. In UK, four breakpoints are identified, and in US, there appear to be five breaks in the mean of inflation. Most breakpoints are precisely computed as implied in tight confidence intervals, except for few occasions, for example the breakdates of 1934a and 1963 in US. In terms of timing

[6] We are grateful to Stephen Cecchetti for useful comments on this point.

[7] We are grateful to Pierre Perron and Zhongjun Qu for making GAUSS codes available and comments on the (im)possibility of accounting for dummy variable effects.

of these breaks, some correspond to changes in the monetary regimes. For example, the breakdates of 1912 and 1914 in UK and US respectively, can be attributed to the change from the Classical Gold Standard to Interwar Gold Standard. Further, the breakdates in early 1980s may be due to the stabilization policies implemented, subsequent to higher inflation rates in late 1970s. However, the breakdates of 1959 and 1963 in UK and US respectively, are hardly attributable to possible regime changes. Nonetheless, the estimates of mean of the inflation across regimes yield interpretable results.

Figure 13: Shifts in the Mean of Inflation



(b) Breaks in the Persistence of inflation

Table 4 reports breakdates and estimates of inflation persistence. The results are based on mean removed data, modelled in an AR(1) specification as described above. Unlike in the case of breaks in the mean, many breakdates are estimated with less precision, as implied by wider confidence intervals. However, the breakdate in early 1980s is more precise and it can correspond to the adoption of flexible exchange rate regime by both countries, because the confidence intervals ranging from [1974:1981] in UK and from [1973:1983] in US. Similarly, we observe another common break in persistence between 1912 and 1914 which may also be referred to shift from Classical Gold Standard to Interwar Gold Standard. The persistence estimates are lower in Classical Gold Standard period in both countries and it shifts up in inter-war years, which marks at 0.659 in UK. Again, there is light increase in the persistence parameter in the flexible exchange rate regime in UK. However, the results for US are not conclusive.

5. Conclusion

This paper attempts to make a contribution to the literature by exploring theoretically and empirically the relationship between inflation persistence and exchange rate regimes using historical data on UK and US inflation series from the mid-ninetieth century onwards. The model developed in this paper is an open economy extension of Barro-Gordon model, with degree of exchange rate flexibility and natural rate shocks to employment, to analyse the implications of different exchange rate regimes on inflation persistence. Despite the fact that Barro-Gordon model is originally developed under flexible price assumptions, the model can well be extended to explain inflation persistence. As described by Reis (2003), both key elements of Barro-Gordon framework i.e., policy objective function and the expectations-augmented Phillips curve can be derived as reduced form relations in a general equilibrium model with nominal rigidities.

Given the main purpose of the paper is to model inflation persistence across different exchange rate regimes, the basic Barro-Gordon framework is extended to an open economy model. The parameter relating to nominal exchange rate flexibility is a modification introduced into the model along with the objective to target the inflation rate of the country, against which the peg is maintained. Both of these new elements in the model play plausible roles in the reduced form solutions. Also, the specification of shocks to natural rate of employment as persistent and transitory components is central in model's implications on inflation persistence.

The model is solved under two alternative assumptions on information availability. In the presence of symmetric information, the model implies inflation persistence due to persistent shocks to the natural rate of employment. The same implication is found in Cukierman (1992) model, however, Cukierman assumes that the public can calculate optimal policy of the policymaker without error. Further, the degree of persistence is determined by the fact that how constraint is the nominal exchange rate, i.e., more constraint a regime implies less persistence and vice versa. However, in the present model, the degree of inflation persistence is independent of the inflation rate of the foreign country, which is contrary to the findings of previous authors. The parameters relating to activist policy and inflation stabilization yield expected results while the former is positively related to inflation persistence and the latter is negatively related.

On the other hand, the model implies more plausible results on inflation persistence in the absence of symmetric information. The key implication of inflation persistence derives from the fact that optimal inflation rate in current period responds to past transitory shocks to the natural rate of employment. The reason for this is, as public does not update information as quickly as policymaker; it cannot fully disentangle previous period innovation to persistent component of employment from the transitory component of employment in that period. Thus, current expectations are affected by past transitory shocks. Because, policymaker partly accommodates current inflation expectations the current inflation is also then affected by transitory shocks. Thus, in the same line of argument of Cukierman, the model implies that asymmetric information results in transforming transitory shocks to natural rate of employment into persistent movements in optimal inflation rate. Consequently, calibration results show a higher inflation persistence coefficient under asymmetric information. However, the persistence coefficient declines at a faster rate under asymmetric information as the exchange rate becomes more constraint.

Further, comparative statics of the model imply that the response of inflation persistence to changes in the degree of exchange rate flexibility is non-linear under both information assumptions. Inflation persistence is more responsive to lower values of exchange rate flexibility, than higher values. However, the response of persistence to changes in the variance of the transitory component of shocks seems to have opposing effects. In the presence of symmetric information, more volatility of transitory shocks brings down inflation persistence while the contrast occurs under asymmetric information. Nonetheless, more volatility in the persistent shocks results in less persistence under asymmetric information. Overall, the persistence component is more responsive to variance parameters under asymmetric information.

In the empirical analysis, the hypothesis that inflation persistence varies with the exchange rate regime is then tested. To allow for time variation in exchange rate regimes, the paper uses historical UK and US data on inflation from 1850 onwards, covering, thus, four distinct exchange rate regime periods, i.e., the Classical Gold Standard, the interwar Gold Standard, the Bretton Woods, and the recent period of floating. The paper employs a number of standard and unknown-break-point tests of structural change (Qu and Perron, 2007). The results suggest that there is considerable time-variation in inflation persistence which can partly be explained by changes in exchange rate regimes. Thus, the empirical analysis leads to the conclusion that the serial correlation of inflation should not be treated as an intrinsic feature of the economy but rather as a historical outcome that is partly contingent upon the macroeconomic policy regime.

The model described in this paper can well be extended on several dimensions. One plausible extension would be to model inflation persistence under overlapping wage contracts. Due to the impact of inflation expectations on future employment, policymaker confronts with contradicting outcomes when responding to current periods shocks to natural rate of employment. Therefore, one channel to explain inflation persistence over time would be through interaction of overlapping wage contracts with policymaker's objective of attaining high employment. Such work would contribute to yet unresolved question of whether to which persistence generating mechanisms i.e. persistence due to shocks to natural rate or persistence due to overlapping wage contracts would be more practically important. Further, the model could account for the effects of exchange rate shocks and costs of exchange rate fluctuations within and between exchange rate regimes. Moreover, it would be interesting to see implications of the model when the effects of exchange rate variability are fully endogenised.

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Table 1: Sub-sample Estimates of Mean Inflation and the Persistence Coefficient

United Kingdom		***GDP Deflator***		***PCE Deflator***		***Com Price Index***		***COL Index***	
		Mean Inflation	ρ	*Mean Inflation*	ρ	*Mean Inflation*	ρ	*Mean Inflation*	ρ
Classical Gold Standards (1860-1913)		0.002 (0.004)	0.109 (0.137)	-0.021 (0.012)	0.165 (0.136)	0.001 (0.003)	0.015 (0.151)	-0.000 (0.003)	-0.048 (0.135)
Interwar Gold Standards	*(1921-1939)*	-0.023 (0.013)	0.141 (0.136)	-0.017 (0.010)	0.172 (0.951)	-0.017 (0.007)	-0.112 (0.165)	-0.021** (0.010)	-0.092 (0.208)
	(1923-1939)	0.003 (0.008)	0.471* (0.086)	0.0003 (0.008)	0.445* (0.103)	-0.002 (0.008)	0.403* (0.121)	-0.002 (0.010)	0.284** (0.134)
Bretton Woods (1946-1972)		0.045* (0.008)	0.402** (0.195)	0.041* (0.007)	0.432** (0.185)	0.043* (0.004)	0.153 (0.206)	0.043* (0.005)	0.219 (0.218)
Floating (1972-1992)		0.087* (0.028)	0.682* (0.176)	0.084* (0.031)	0.770* (0.154)	0.087* (0.024)	0.662* (0.187)	0.096* (0.023)	0.550** (0.212)
Inflation Targeting (1992 onwards)		0.025* (0.003)	0.373** (0.179)	0.022* (0.003)	0.436* (0.098)	0.026* (0.002)	0.099 (0.194)	--	--

United States		***GNP Inflation***		***CPI Inflation***		***PCE Inflation***	
		Mean Inflation	ρ	*Mean Inflation*	ρ	*Mean Inflation*	ρ
Greenback (1861-1878)		-0.007 (0.052)	0.531** (0.224)	-0.004 (0.046)	0.601* (0.213)	--	--
Classical Gold Standard (1879-1914)		0.005 (0.006)	0.106 (0.159)	0.003 (0.005)	0.264* (0.130)	--	--
Interwar Period (1923-1939)		-0.009 (0.018)	0.413*** (0.228)	*AR(3)* -0.356 (2.034)	0.936** (0.232)	-0.016 (0.044)	0.596*** (0.302)
Bretton Woods	*(1946-1971)*	*AR(2)* 0.032* (0.006)	0.300 (0.199)	*AR(2)* 0.030* (0.007)	0.240 (0.189)	0.028* (0.008)	0.509* (0.176)
	(1946-1973)	*AR(2)* 0.034* (0.006)	0.327*** (0.191)	*AR(2)*0.033* (0.007)	0.255 (0.190)	0.029* (0.008)	0.516* (0.172)
Floating (1972-2006)		*AR(2)* 0.038* (0.012)	0.845* (0.081)	*AR(2)* 0.045* (0.011)	0.699* (0.119)	0.037** (0.018)	0.889* (0.092)

*Note: Standard errors are in parentheses. *, **, and *** indicate significance levels 1%, 5%, and 10%, respectively. Serial Correlation LM tests are carried out and results confirm that there is no issue of serial correlation in all sub-samples except the UK 'Interwar Gold Standards' for the period 1921-1939. Therefore, that regime is redefined as 1923-1939. Results improve significantly, with, however, substantial degree of persistence. For US, where there is evidence of serial correlation an AR(2) model is estimated..*

Table 2: Estimates of Mean Inflation and the Persistence Coefficient (Full-sample with Regime Effects)

United Kingdom	*GDP Deflator*		*PCE Deflator*		*Com Price Index*		*COL Index*	
	Mean Inflation	ρ	*Mean Inflation*	ρ	*Mean Inflation*	ρ	*Mean Inflation*	ρ
Classical Gold Standards	0.002 (0.005)	0.109 (0.156)	0.002 (0.004)	0.104 (0.157)	0.002 (0.008)	0.456* (0.122)	0.001 (0.007)	0.297*** (0.181)
Interwar Gold Standards	0.002 (0.019)	0.471* (0.192)	0.0003 (0.015)	0.445** (0.189)	-0.0003 (0.016)	0.428** (0.209)	-0.001 (0.012)	0.149 (0.359)
Bretton Woods	0.041* (0.009)	0.198 (0.304)	0.037* (0.007)	0.147 (0.295)	0.041* (0.008)	0.204 (0.298)	0.093 (0.063)	0.628* (0.174)
Floating	0.081* (0.027)	0.688* (0.160)	0.077* (0.032)	0.776* (0.150)	0.078* (0.028)	0.723* (0.155)	0..123 (0.095)	0.727* (0.139)
Inflation Targeting	0.024*** (0.013)	0.239 (1.300)	0.022 (0.014)	0.376 (0.928)	0.026* (0.007)	-0.230 (1.301)	-0.846 (0.954)	0.679 (0.146)
Dummy1918	0.108* (0.023)		0.119* (0.019)		0.120* (0.022)		0.120* (0.027)	
Dummy1940	0.065* (0.023)		0.068* (0.019)		0.067* (0.021)		0.072* (0.024)	
No. of Observations	157		157		157		141 (after adjusting end points)	
R- squared	0.607		0.685		0.662		0.592	
LM Statistic	0.160		0.637		0.500		0.202	

*Notes: Standard errors are in parentheses. *, **, and *** indicate significance levels 1%, 5%, and 10%, respectively. For AR (p) models where p >1, estimates of the* $\Delta\pi_{t-1}$ *are not reported as it is a not a parameter of interest. The Breusch-Godfrey Lagrange Multiplier test is the most appropriate for testing serial correlation when the lagged dependent variables exist in the regression. The probability value for rejecting the null hypothesis of 'no serial correlation' is reported.*

Contd;

Table 2: Estimates of Mean Inflation and the Persistence Coefficient (Full-sample with Regime Effects)

United States	*GNP Inflation (1869-2006)*		*CPI Inflation (1850-2006)*		*PCE Inflation - AR(3) (1929-2006)*	
	Mean Inflation	ρ	*Mean Inflation*	ρ	*Mean Inflation*	ρ
Greenback	-0.007 (0.038)	0.532* (0.164)	-0.004 (0.031)	0.601* (0.146)	--	--
Classical Gold Standards	0.005 (0.007)	0.106 (0.183)	0.003 (0.009)	0.264 (0.259)	--	--
Interwar Period	-0.009 (0.016)	0.413** (0.200)	-0.008 (0.017)	0.375 (0.237)	0.010 (0.010)	0.273*** (0.139)
Bretton Woods	0.026*** (0.015)	0.439*** (0.274)	0.026 (0.017)	0.462*** (0.253)	0.024* (0.007)	0.428* (0.165)
Floating	0.021 (0.054)	0.843* (0.284)	0.037 (0.032)	0.757* (0.252)	0.035** (0.018)	0.818* (0.128)
Dummy1917-19	0.084* (0.032)		0.099* (0.028)		--	
Dummy1942-45	0.021 (0.021)		0.019 (0.023)		0.029 (0.023)	
Vietnam War Dummy	0.007 (0.015)		0.008 (0.016)		0.008 (0.07)	
No. of Observations	136		155		74	
R- squared	0.383		0.409		0.668	
LM Statistic	0.891		0.119		0.001	

*Notes: Standard errors are in parentheses. *, **, and *** indicate significance levels 1%, 5%, and 10%, respectively. For AR (p) models where p >1, estimates of the $\Delta\pi_{t-1}$ are not reported as it is a not a parameter of interest. The Breusch-Godfrey Lagrange Multiplier test is the most appropriate for testing serial correlation when the lagged dependent variables exist in the regression. The probability value for rejecting the null hypothesis of 'no serial correlation' is reported.*

Table 3: Breakdates and Estimates of Unconditional Mean of Inflation

			Breakdates		
UK	--	1912	1935	1959	1982
		[1911:1939]	[1929:1936]	[1952:1959]	[1980:1984]
US	1894	1914	1934	1963	1983
	[1893:1898]	[1913:1926]	[1898:1935]	[1952:1975]	[1983:1986]
			Estimates		
		Regime	**UK**	**Regime**	**US**
		1850-1911	0.004	1870-1893	-0.016
		1912-1934	-0.014	1894-1913	0.018
		1935-1958	0.039	1914-1933	-0.012
		1959-1981	0.084	1934-1962	0.028
		1982-2006	0.036	1963-1982	0.056
		--	--	1983-2006	0.025

Notes: Breakdates and estimates are based on Qu and Perron (2007) procedure. 90 percent confidence intervals are reported below each breakdate. The estimates during war periods, have been refined by using war dummies.

Table 4: Breakdates and Estimates of Inflation Persistence

				Breakdates	
UK	1880	1912	1935	--	1980
	[1850:1882]	[1911:1948]	[1887:1940]		[1974:1981]
US	1893	1914	--	1951	1982
	[1885:1897]	[1913:1919]		[1919:1952]	[1973:1983]
				Estimates	
		Regime	**UK**	**Regime**	**US**
		1850-1879	0.069	1870-1892	-0.069
		1880-1911	0.242	1893-1913	0.151
		1912-1934	0.659	1914-1950	0.257
		1935-1979	0.666	1951-1981	0.807
		1980-2006	0.775	1982-2006	0.748

Notes: Breakdates and estimates are based on Qu and Perron (2007) procedure. 90 percent confidence intervals are reported below each breakdate. The estimates during war periods, have been refined by using war dummies.

Appendix A
Derivation of equation (4.35)

Using equations (4.19) and (4.21) to form:

$$\pi_t - g(t) = (K_1 + \delta K_4)\upsilon_t + K_1\varepsilon_t ,$$

and substituting (4.29) and (4.30) into (4.23) with the above expression:

$$\pi^e_{t+1} = \frac{1}{1 - \frac{\alpha^2(1-d)}{[(1-d)(\lambda+\alpha^2)+d]}}\left\{\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} + K_4\right)H + K_3\pi^f_{t+1}\right.$$

$$+\delta^2\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} + \delta K_4\right)u_{t-1}$$

$$+\delta\theta\left[\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} + \delta K_4\right)\upsilon_t + \frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]}\varepsilon_t\right]$$

Expanding terms,

$$\pi^e_{t+1} = \frac{(1-d)(\lambda+\alpha^2)+d}{(1-d)\lambda+d}\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} + K_4\right)H + \frac{[(1-d)(\lambda+\alpha^2)+d]}{(1-d)\lambda+d}\left(K_3\pi^f_{t+1}\right)$$

$$+\frac{[(1-d)(\lambda+\alpha^2)+d]}{(1-d)\lambda+d}\delta^2\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} + \delta K_4\right)u_{t-1}$$

$$+\frac{[(1-d)(\lambda+\alpha^2)+d]}{(1-d)\lambda+d}\delta\theta\left[\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} + \delta K_4\right)\upsilon_t + \frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]}\varepsilon_t\right]$$

Rearranging terms and taking one period lag yields the equation (4.35):

$$\pi^e_t = \frac{(1-d)(\lambda+\alpha^2)+d}{(1-d)\lambda+d}\left[\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} + K_4\right)H + K_3\pi^f_t\right]$$

$$+\frac{[(1-d)(\lambda+\alpha^2)+d]}{(1-d)\lambda+d}\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]} + \delta K_4\right)$$

$$\cdot\left[\delta^2 u_{t-2} + \delta\theta\left(\upsilon_{t-1} + \frac{\alpha(1-d)}{\alpha(1-d) + \delta\left[(1-d)(\lambda+\alpha^2)+d\right]K_4}\varepsilon_{t-1}\right)\right].$$

Appendix B

Derivation of equation (4.36)

Substituting equations (4.29) and (4.30) into (4.23) and rearranging yields,

$$\pi^e_{t+1} = \frac{(1-d)(\lambda+\alpha^2)+d}{(1-d)\lambda+d}\left\{\left(\frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]} + K_4\right)H + K_3\pi^f_{t+1}\right.$$
$$+\delta^2\left(\frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]} + \delta K_4\right)u_{t-1}$$
$$\left.+\left(\frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]} + \delta K_4\right)\delta\theta\left[\upsilon_t + \frac{\alpha(1-d)}{\alpha(1-d) + \left[(1-d)(\lambda+\alpha^2)+d\right]\delta K_4}\varepsilon_t\right]\right\}$$

(B.1)

Taking conditional expectations of equation (4.27) and subtracting the resulting equation from (4.27) yields,

$$\pi_t - \pi^e_t = \frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]}\left[\delta\left(\upsilon_{t-1} - E\left[\upsilon_{t-1} \mid I_t\right]\right) + \upsilon_t + \varepsilon_t\right]$$
$$+ K_4\left[\delta^2\left(\upsilon_{t-1} - E\left[\upsilon_{t-1} \mid I_t\right]\right) + \delta\upsilon_t - \alpha E_{G,t}\left[\pi_{t+1} - \pi^e_{t+1}\right]\right] \qquad \text{(B.2)}$$

Substituting (4.19) into (4.20) yields,

$$E\left[\upsilon_t \mid I_{t+1}\right] = \left(\frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]} + \delta K_4\right)\theta\left[\upsilon_t + \frac{\alpha(1-d)}{\alpha(1-d) + \left[(1-d)(\lambda+\alpha^2)+d\right]\delta K_4}\varepsilon_t\right]$$

(B.3)

Leading (B.2) by one period and substituting (B.3) into the resulting equation yields,

$$\pi_{t+1} - \pi^e_{t+1} = \left(\frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]} + \delta K_4\right)$$
$$\left[\delta(1-\theta)\upsilon_t - \delta\theta\left(\frac{\alpha(1-d)}{\alpha(1-d) + \left[(1-d)(\lambda+\alpha^2)+d\right]\delta K_4}\right)\varepsilon_t + \upsilon_{t+1}\right]$$
$$+ \frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]}\varepsilon_{t+1} - K_4\alpha E_{G,t}\left[\pi_{t+2} - \pi^e_{t+2}\right] \qquad \text{(B.4)}$$

Equation (B.4) implies that unexpected inflation in $t+1$ depends on realizations of shocks in periods $t, t+1$ and later periods, and not on earlier periods.

Also the last term in equation (B.4) implies:

$$E_{G,t}\left\{E_{G,t+1}\left[\pi_{t+2}-\pi_{t+2}^{e}\right]\right\}=E_{G,t+1}\left[\pi_{t+2}-\pi_{t+2}^{e}\right]=0 \qquad \text{(B.5)}$$

The first equality is a result of the law of iterated projections, and second equality is because policymaker's information does not include shocks to be realized from period $t+1$ onwards. Taking conditional expectation of (B.4), given information set of policymaker in period t ,

$$E_{G,t}\left[\pi_{t+1}-\pi_{t+1}^{e}\right]=\delta\left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}+\delta K_{4}\right)(1-\theta)\upsilon_{t}-\delta\theta\left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}\right)\varepsilon_{t} \qquad \text{(B.6)}$$

Substituting (B.1) with a one period lag, and (B.6) into (4.27), using the results $h_t \equiv H + u_t + \varepsilon_t$ and $E_{G,t}h_{t+1} = H + \delta u_t$,

$$\begin{aligned}
\pi_{t} = {} & \frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}\left[H+u_{t}+\varepsilon_{t}\right] \\
& + \frac{\alpha^{2}(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}\left\{\frac{(1-d)\left(\lambda+\alpha^{2}\right)+d}{(1-d)\lambda+d}\left[\left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}+K_{4}\right)H+K_{3}\pi_{t}^{f}\right.\right. \\
& + \delta^{2}\left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}+\delta K_{4}\right)u_{t-2} \\
& \left.\left. + \left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}+\delta K_{4}\right)\delta\theta\left(\upsilon_{t-1}+\frac{\alpha(1-d)}{\alpha(1-d)+\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]\delta K_{4}}\right)\varepsilon_{t-1}\right]\right\} \\
& + \frac{d}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}\pi_{t}^{f} \\
& - \frac{\alpha\beta\delta^{2}(1-d)}{1-K_{2}}\theta\left(H+\delta u_{t}\right) \\
& + \frac{\alpha^{2}\beta\delta^{2}(1-d)}{1-K_{2}}\theta\left[\delta\left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}+\delta K_{4}\right)(1-\theta)\upsilon_{t}-\delta\theta\left(\frac{\alpha(1-d)}{\left[(1-d)\left(\lambda+\alpha^{2}\right)+d\right]}\right)\varepsilon_{t}\right]
\end{aligned} \qquad \text{(B.7)}$$

Expanding equation (B.7) using the definition for $K_4 = -\frac{\alpha\beta\delta^2(1-d)}{1-K_2}\theta$, and after some rearrangements yields equation (4.36).

Appendix C
Derivation of equation (4.37)

Taking one period lag of equation (4.36);

$$\pi_{t-1} = \frac{\left(\alpha(1-d) + \left[(1-d)(\lambda+\alpha^2)+d\right]K_4\right)}{(1-d)\lambda+d}H + \left(\frac{d}{(1-d)\lambda+d}\right)\pi_t^f$$

$$+\frac{\left(\alpha(1-d) + \left[(1-d)(\lambda+\alpha^2)+d\right]\delta K_4\right)}{(1-d)\lambda+d}\delta^2 u_{t-3}$$

$$+\left(\frac{(1-d)(\lambda+\alpha^2\theta)+d}{(1-d)\lambda+d}\right)\left(\frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]}+\delta K_4\right)\delta\upsilon_{t-2}$$

$$+(1-\alpha\delta(1-\theta)K_4)\left(\frac{\alpha(1-d)}{\left[(1-d)(\lambda+\alpha^2)+d\right]}+\delta K_4\right)\upsilon_{t-1}+\frac{(1+K_4\alpha\delta\theta)}{\left[(1-d)(\lambda+\alpha^2)+d\right]}\alpha(1-d)\varepsilon_{t-1}$$

$$+\left(\frac{\alpha^3(1-d)^2}{((1-d)\lambda+d)\left[(1-d)(\lambda+\alpha^2)+d\right]}\right)\delta\theta\varepsilon_{t-2}. \qquad \text{(C.1)}$$

Taking unconditional expectations of equation (4.36);

$$E_t\pi_t = \frac{\left(\alpha(1-d) + \left[(1-d)(\lambda+\alpha^2)+d\right]K_4\right)}{(1-d)\lambda+d}H + \left(\frac{d}{(1-d)\lambda+d}\right)\pi_t^f. \qquad \text{(C.2)}$$

Using equations C.1 and C.2 in the statistical result for covariance yields;

$$Cov(\pi_t, \pi_{t-1}) = E_t(\pi_t - E_t\pi_t)(\pi_{t-1} - E_t\pi_t) =$$

$$\left[\left(\frac{(1-d)(\lambda+\alpha^2\theta)+d}{(1-d)\lambda+d}\right)(1-\alpha\delta(1-\theta)K_4)\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]}+\delta K_4\right)^2\delta\sigma_\upsilon^2\right]$$

$$+\left[\left(\frac{\alpha^4(1-d)^3(1+K_4\alpha\delta\theta)}{((1-d)\lambda+d)[(1-d)(\lambda+\alpha^2)+d]^2}\right)\delta\theta\sigma_\varepsilon^2\right]. \qquad \text{(C.3)}$$

Similarly using equation (4.36) and (C.2) in the statistical result for variance yields;

$$Var = E_t(\pi_t - E_t\pi_t)^2 =$$

$$\frac{(\alpha(1-d)+[(1-d)(\lambda+\alpha^2)+d]\delta K_4)^2}{[(1-d)\lambda+d]^2}\delta^4\sigma_u^2$$

$$+\left(\frac{\alpha(1-d)}{[(1-d)(\lambda+\alpha^2)+d]}+\delta K_4\right)^2\left[\left(\frac{(1-d)(\lambda+\alpha^2\theta)+d}{(1-d)\lambda+d}\right)^2\delta^2+(1-\alpha\delta(1-\theta)K_4)^2\right]\sigma_\upsilon^2$$

$$+\left(\frac{\alpha^2(1-d)^2\delta^2\theta^2}{[(1-d)(\lambda+\alpha^2)+d]^2}\right)\left[(1+K_4\alpha)^2+\frac{\alpha^4(1-d)^2}{[(1-d)\lambda+d]^2}\right]\sigma_\varepsilon^2. \qquad \text{(C.4)}$$

Dividing equation (C.3) by (C.4) and with some rearrangements yields the equation (4.37).

Data Appendix

United Kingdom

(1). Implicit GDP Price Deflator and the Personal Consumption Expenditure (PCE) Deflator (for the period 1850-1980)

Source: Mitchell, B.R., (1988): British Historical Data, The Cambridge University Press.

(2). Implied GDP deflator: Gross value added at basic prices

Source: Office for National Statistics.
http://www.statistics.gov.uk/statbase/TSDSelection1.asp
Series code: pn2: A1: CGBV- Gross value added at basic prices: Implied deflator (2003=100), Seasonally adjusted.

(3). Personal Consumption Expenditure (PCE) Deflator (for the period 1948-2006)

Source: Office for National Statistics, National Accounts Tables

Series code: *ABJQ: Total national concept consumption, at current prices*
(Dataset Name: natpe2), Household final consumption expenditure at current prices: Goods and services (seasonally adjusted)

Series code: *HAYE: Domestic expenditure at market prices, Final consumption by non-profit institutions at current prices*
(Dataset Name: natpc1), GDP: expenditure at current market prices, (seasonally adjusted)

Series code: *ABJR: Total national concept consumption, chained volume measures*
(Dataset Name: natpe4), Household final consumption expenditure Goods and services (seasonally adjusted)

Series code: *HAYO: Domestic expenditure at market prices, Final consumption by non-profit institutions, at chained volume measures*
(Dataset Name: natpc2), GDP: expenditure chained volume measures at market prices (seasonally adjusted)

(4). Composite Price Index and annual change (1974 =100)

Source: Office for National Statistics (RPI all items)
http://www.statistics.gov.uk/statbase/TSDdownload1.asp.
Series code: mm23: 3.6: CDKO- Long term indicator of prices of consumer goods and services (Jan 1974=100), not seasonally adjusted.
Series code: mm23: 3.6: CDSI- Annual percentage change of long term indicator of prices of consumer goods and services (Jan 1974=100), not seasonally adjusted.
O'Donoghie, J, Goulding, L., and Allen, G. (2004): 'Consumer Price Inflation since 1750', Office for National Statistics and House of Commons Library- Economic Policy and Statistics Section. (http://www.statistics.gov.uk/cci/article.asp?ID=726),

(5). Cost of Living Index (1913=100)

This is obtained from Scholliers, P. and Zamagni, V., (1995): Labour's Reward: Real wages and economic change in 19th- and 20th-century Europe, Edward Elgar Publishing Ltd., England. In the Appendix, Table A.24 (pp. 263-66) by C. H. Feinstein provides cost living series for the United Kingdom from 1780 to 1990.

(6). GDP Deflator (1913 = 100)

Source: Feinstein, C. H., (1972): National Income, Expenditure and Output of the United Kingdom, 1855-1965, The Cambridge University Press, Cambridge.

Table 61, 'Price indices for main categories of goods and services' 1870-1965, column (7), pp.T132-33.

(7). Implicit Price Deflator (1929 = 100)

Source: Friedman, M. and Schwartz A. J., (1982): Monetary Trends in the United States and the United Kingdom, Their Relation to Income, Prices, and Interest rates 1867–1975, The University if Chicago Press, Chicago and London. Table 4.9: Annual Data for United Kingdom, Column (4).

United States

(1). GNP Deflator Series (1982 = 100)

Source: Romer, C.,(1989): The Prewar Business Cycle Reconsidered: New Estimates of Gross National Product, 1869-1908, *Journal of Political Economy*, vol.97, No.1,(pp.1-37).

(2). Implicit Price Deflator (1929 = 100)

Source: Friedman, M. and Schwartz A. J., (1982): Monetary Trends in the United States and the United Kingdom, Their Relation to Income, Prices, and Interest rates 1867– 1975, The University if Chicago Press, Chicago and London. Table 4.8: Annual Data for United States, Column (4).

(3). GNP Deflator Series (1972 = 100)

Source: Gordon, R. J. (1986): The American Business Cycles: Continuity and Change, The University of Chicago Press.
Appendix B, Historical Data (Balke, S. and Gordon, R. J.), pp. 781-83.

(4). Implicit Price Deflators (2000 = 100)

Source: National Income and Product Accounts Tables, *Bureau of Economic Analysis*

http://www.bea.gov/ T*able 1.1.9. Implicit Price Deflators for Gross Domestic Product* (Seasonally adjusted)

(5). Consumer Price Index, All Items (1967=100) from 1850 to 1870

Source: Historical statistics of the United States : colonial times to 1970 (1976), Bicentennial ed., Bureau of the Census, Washington, D.C. 1976. (Part A), pp.210-11. Series Code: E 135-166

(6). Consumer Price Index-All Urban Consumers, All Items (1982-84=100)

Source: U.S. Department of Labor, Bureau of Labor Statistics
http://www.bls.gov/home.htm
SeriesID:CUUR0000SA0(not seasonal adjusted) (01/1913-12/2006)

(7). Implicit Price Deflators of Personal Expenditure (2000 = 100)

Table 1.1.9. Implicit Price Deflators for Gross Domestic Product
(Seasonally adjusted)
Source: National Income and Product Accounts Tables, *Bureau of Economic Analysis*, http://www.bea.gov/
Series Code: A002RD3: Personal consumption expenditures