INVESTIGATING INFLATION PERSISTENCE IN SRI LANKA: HAS THE INFLATION PROCESS CHANGED?

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ABSTRACT

High inflation persistence implies long-run effects of a shock to inflation, and, consequently, may involve high disinflation costs. Why inflation is more persistent in certain periods, than in others? Is inflation persistence a structural feature of the economy, such that, eradicating it may involve some significant loss of economic activity; or does it vary with the stability and transparency of monetary policy regimes? These are some of the issues, which attracted a lot of research interest among academics and policymakers alike, over the years. This paper examines inflation persistence in Sri Lanka from 1960q1-2009q4, a period of high variation in inflation and some significant policy changes. By employing both classical and Bayesian models, we find that inflation persistence has been high and almost unchanged during 1970s and 1980s; it starts falling since early-1990s; and at present, it stands at some moderate levels. Meanwhile, the CPI inflation process has been subject to significant parameter instability over the sample period, in that, during late-1970s through 1980s, it has been very close to a unit root process (implying long-run effects of an inflation shock), and currently, it is not well-characterized as a process with a unit root. We find that, during the period of high inflation persistence, inflation dynamics are mainly driven by shocks to the trend component, making inflation sticky at some higher levels. By contrast, during recent years, the effects of inflation shocks turn out to be transitory, resulting relatively lower degree of persistence. Further, we document evidence of some significant moderation of innovation variance of inflation and output growth, in recent years. By weighing all the evidence, we conclude that inflation persistence has shown significant time-variation, as such, we take side with those who claim that inflation persistence need not be 'hardwired' into the deep structure of the economy.

Keywords: Inflation Persistence, Monetary Policy, Structural Breaks, Time-Varying Parameter Models

JEL Classification: C11, E31, E52

1 INTRODUCTION

A high degree of inflation persistence implies long-run effects of a shock to inflation, i.e., given a shock that raises inflation today, will take a longer time to die out.[1] Moreover, if the inflation process is highly persistent, reducing inflation may involve some 'sacrifice' of economic activity

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[1] A straightforward definition of inflation persistence is "the time it takes for an inflation shock to dissipate" (Sbordone, 2007, p.1312). Also, Batini and Nelson (2001; 2002) offer three working definitions of inflation persistence: (a) positive serial correlation in inflation; (b) lags between systematic monetary policy actions and their (peak) effect on inflation; and (c) lagged response of inflation to non-systematic policy actions (i.e., policy shocks).

(i.e., high disinflation costs). Thus, a good understanding of the degree of persistence in the inflation process may be crucial in achieving low and stable inflation rates. In particular, given a shock that raises inflation today, policymakers are keen to know the following: (a) by how much do we expect inflation to be higher at some future date, say by next quarter; and (b) how long will it take to return to the previous level (Pivetta and Reis, 2007). Also, as Stock (2004) describes examining inflation persistence may be important for policymakers in various ways, such as, improving inflation forecasts; understanding the dynamic effects of exogenous price shocks; informing and refining the conduct of monetary policy; and, assessing whether different monetary regimes produce different persistence. Thus, given the importance of understanding the degree of inflation persistence in pursuing appropriate monetary policy, there has been a voluminous research on this subject across the board.[2] However, to our knowledge, a detailed investigation on inflation persistence in Sri Lanka is yet to be carried-out, with the exception of Harischandra (2007), which employs classical estimation techniques to examine inflation persistence across exchange rate regimes in Sri Lanka. However, in the present study, we move beyond our previous work by employing both classical and Bayesian estimation techniques, thus, offering more insights into the question at hand.

Over the last fifteen years or so, there have been significant developments in modelling and estimating inflation persistence. Many authors argue that inflation persistence is an inherent characteristic of the economy, and, as such, propose macroeconomic models with wage- and price-adjustment that embed inflation persistence into the behaviour of optimizing agents. Some of these key theoretical developments are: the relative real wage contracting models of Buiter and Jewitt (1989) and Fuhrer and Moore (1995); backward-looking rule-of-thumb price setting of Galí and Gertler (1999); sticky-information models of Mankiw and Reis (2002), imperfect-credibility models of Erceg and Levin (2003), price-indexation models of Christiano *et al.*, (2005) etc. Given all these alternative mechanisms through which inflation persistence is generated endogenously; some options seem to be more preferred than others. For example, as Woodford (2007) describes, there is a variety of possible interpretations of the apparent need for inertia in the inflation process that are more appealing than simple indexation hypothesis. According to him, such interpretations may be based on: (a) generalizing the Calvo model of staggered price adjustment, in that, the probability is a function of the time that the price has been fixed (see

[2] For example, the Inflation Persistence Network (IPN) at the European Central Bank is tasked with investigating inflation persistence in the Euro area (see Angeloni *et al.*, 2005; for a summary of results). Also, see Cogley and Sargent (2005), Pivetta and Reis (2007), Stock and Watson (2007), among others, on the US economy.

Sheedy, 2007); (b) log-linearising structural equations around steady-state values associated with a time-varying trend inflation, rather than around a zero-inflation steady state (see Cogley and Sbordone, 2008); (c) incorporating explicit models of expectation formation (*learning dynamics*), which allows for departures from rational expectations (see Erceg and Levin, 2003; Orphanides and Williams, 2004; Milani, 2005).

More recently, another branch of the literature has cast doubt on treating serial correlation of 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, thus questioning the notion that intrinsic inflation persistence found by many researchers is structural in the sense of Lucas (1976). There is now well-documented empirical evidence that inflation exhibits substantial level of persistence over time, whatever may be its structural source.[3] Also, recognizing the time-varying nature of inflation persistence, several authors examine potential forces which may be behind such changes. One of such leading candidates is a change in the monetary regime, as hypothesized by Alogoskoufis and Smith (1991), Bordo and Schwartz (1997), Benati (2008), among others. This literature suggests that the key to achieving low and stable inflation rates is a credible *nominal anchor*, whether it be a target inflation rate, monetary aggregate or the exchange rate. For example, the gold-convertibility principle during the Classical-gold-standard period has gained public confidence as a time-consistent commitment mechanism which resulted in stable price levels and exchange rates. Further, adopting of inflation targeting by several advanced economies may be behind many successful inflation stories in the 1990s, compared to where there were no such policies (see, for example, Siklos and Weymark, 2009). Recently, Benati (2008) carries out a fairly extensive investigation on inflation persistence across historical monetary regimes in several advanced economies. He concludes that under stable monetary regimes with a 'clearly defined nominal anchor' (such as Classical-gold-standard regime and recent inflation-targeting regime in several advanced economies) intrinsic persistence is remarkably low. However, some authors document evidence showing that inflation

[3] On the sources of persistence Angeloni *et al.* (2005) provides a general description based on a structural inflation equation of hybrid NKPC i.e., : $\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t(\pi_{t+1}) - \lambda \hat{\mu}_t + \xi_t$, where π_t is inflation, $\hat{\mu}_t$ deviation of actual mark-up from the desired level, and ξ_t is exogenous mark up shock. E_t is the expectations operator. Accordingly, the sources of inflation persistence correspond to each term in the right-hand side of this specification, 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 error term if it is serially correlated (error term persistence). However, as Angeloni *et al.* (2005) describes "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 depend on the monetary policy regime and the policy reaction function" (p.4).

persistence may change due to various other factors, apart from changes in monetary regimes. Those factors may include major wars, oil price shocks, changes in the monetary policy framework etc., (Burdekin and Siklos, 1999, among others). This brief discussion on the literature is intended to highlight the controversy remaining over modelling and estimating the degree of inflation persistence, despite voluminous research on the field. As such, there is only little consensus on whether inflation persistence is an inherent feature of the economy; or instead, it depends on the policy regime. If inflation persistence is time-varying, what factors cause it?

To motivate the issue in the context of Sri Lankan economy, we plot in Figure 1 a profile of inflation rates measured by CPI and GDP deflator index since 1960, covering a major part of the history of the Central Bank of Sri Lanka.[4]

It is clearly evident that inflation rates show some substantial time-variation over the sample period. In particular, inflation rates are relatively low from 1960 through mid-1970s; and by the late-1970s, they increase dramatically to record high levels, following a huge wave of shocks to the price level with the implementation of economic liberalization policies in late 1977. These high inflation rates tend to stay up there for a major part of 1980s. Since early-1990s, however, inflation tends to be declining to a greater extent. During the very recent years, inflation experience has been quite unprecedented, in that, inflation rises and falls within a very shorter period of time. Intriguingly, inflation rates, at present, tend to say at lower levels, in comparison to the experience in late-1970s, where inflation rates continued to be highly volatile following the major upward shift. Several factors may have contributed for this, such as, stringent monetary policy measures adopted by the Central Bank, developments in the domestic and international front which may include easing of oil-price pressure, declining trend of the aggregate demand due to economic slowdown etc. Overall, Figure 1 points towards three distinguishable high inflation episodes in Sri Lanka in the post-1960 period, and they occur during 1978-1984, 1988-1993, and 2007-2008. It would be interesting to know, why during 1978-1984, inflation goes up and tends to stay there for a considerable period of time, while during 2007-2008, inflation falls rather quickly from higher levels, and more importantly, it tends to settle low levels.

[4] The Central Bank was established by the Monetary Law act No.58 of 1949 and commenced operations in August 1950, thus ending the Currency Board System which was set up under the Paper Currency Ordinance No.32 of 1884.

1.1 MODELLING AND ESTIMATION ISSUES

Before proceeding, it may be worth highlighting some issues relating to modelling and estimating of inflation persistence, and how we intend to address them in this study. First, it is now widely recognised that when estimating persistence in a univariate inflation process, any shifts (or structural breaks) in the mean inflation need to be properly accounted for, failing which may result in biased estimates of persistence (Perron, 1990). However, a key issue many applied macroeconomists face in there is that how many mean breaks to be allowed for. This is important because allowing for 'too many' breaks in the mean inflation may result in underestimating the degree of persistence. For example, Cecchetti and Debelle (2006) show that persistence estimates decline significantly when the number of mean shifts increases. To remedy that, the traditional breakpoint testing procedures, such as, Chow (1960) tests are less helpful, because, they are fraught with a key limitation of assuming breakdates known a *priori*, which may end up in 'misleading' results because the tests may wrongly indicate breakdates when there are actually no breaks (see Hansen, 2001). Therefore, we employ the latest breakpoint testing procedures, which require no prior information on possible breakdates, and the tests can detect multiple breaks given the data series. Two such procedures employed are: Andrews and Ploberger (1994) and Qu and Perron (2007) tests.[5]

Second, it is well known that the least-squares estimator may be biased downward as the estimates of the persistence parameter approaches unity (Levin and Piger, 2004). This is called 'median-bias' which is the difference between the median of the estimator and the *true* parameter value. To remedy this, Hansen (1999) describes a procedure known as median-unbiased-estimator (MUE), which corrects for any biasedness in standard least-squares estimates. Subsequently, many studies use Hansen's (1999) 'grid' bootstrap procedure to obtain bias-adjusted point estimates of inflation persistence and its confidence intervals.[6] Following this strand of literature, we measure the degree of persistence using the MUE estimator.

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[5] A key difference between the two is; the former detects only a single break at a time, while the latter is capable of detecting multiple breaks simultaneously.

[6] Grid bootstrap procedure is an improved procedure over conventional bootstrap methods used for constructing confidence intervals. Particularly, in autoregressive models, it is known that conventional bootstrap methods fail to provide correct first-order asymptotic coverage when AR coefficient is close to unity. Obtaining confidence intervals is more appropriate, as the standard *t*-statistic is a poor normal approximation for large AR coefficient estimates. Bootstrap procedure replaces the asymptotic sampling distribution by an exact distribution that acts as if the empirical distribution of the sample is the population distribution (Hansen, 1999).

Third, the recent literature highlights that understanding of inflation persistence may require accounting for any time-variation in the trend inflation. For example, Cogley and Sbordone (2008) describe that "[i]nflation is highly persistent, but much of that persistence is due to shifts in trend inflation" (p.2118). This interpretation may have a direct relevance to us because, the inflation rates in Sri Lanka (as depicted in Figure 1) are very high and tend to remain high in certain periods, while in others, high inflation rates decline rather quickly to long-run trend levels. Thus, we intend to obtain time-varying estimates of persistence by allowing for shifts in trend inflation, using the procedure described in Stock and Watson (2007), namely, unobserved components-stochastic volatility (UC-SV) models (see also, Cecchetti et al., 2007).

Finally, the inflation process is more likely to be affected by a mixture of shocks (such as policy shocks and shocks to other macroeconomic variables). Thus, we move beyond the univariate modelling of the UC-SV framework, and employ a multivariate model based on a vector-autoregressive (VAR) process. This may offer more insights into the time-variation in the inflation process, along with other sources of uncertainty in the economy. Recently, there have been some significant developments in the VAR literature. Some authors report that changes in macroeconomic variables are explained fairly well by the changes in the variance (heteroscedasticity) of exogenous shocks (see, Stock and Watson, 2002; Sims and Zha, 2004; among others); while others claim that the transmission mechanism (i.e., the manner in which macroeconomic variables respond to shocks) may change as well (Cogley and Sargent, 2001; Bovin and Giannoni, 2006; among others).[7] Consequently, several authors attempt to combine these two classes of explanations, and model time-varying parameter vector-autoregressive (TVP-VAR) models with stochastic volatility, in that, both the VAR coefficients and the variance covariance matrix of the innovations are allowed to change (see Primiceri, 2005; Cogley and Sargent, 2005; and Koop *et al*., 2009). In this study, despite our primary purpose is to document evidence on inflation persistence, we attempt to employ a TVP-VAR model with stochastic volatility, in order to estimate time-varying volatility in the inflation process in a multivariate context. The exercise may help to shed some light on any potential link between the variance of shocks to the inflation process and variance of shocks to other key macroeconomic variables.

[7] Note, however, that the evidence of changes in the systematic part of monetary policy may be controversial, because some authors find little or no evidence in favour (e.g., Bernanke and Mihov, 1998; in the context o the US economy).

1.2 MAIN FINDINGS

We provide below a brief preview our main results. First, the least-squares estimates suggest that CPI inflation has been highly persistent during 1970s and 1980s (as much as 0.89, at times); and since early-1990s, persistence has been declining towards some moderately high levels (around 0.60) by the end of the sample. Further, structural breakpoint tests suggest strong evidence of parameter instability in the inflation processes, in that, breaks occur in both the mean and persistence parameter. The mean breaks occur around 1967q3, 1978q2, 1986q2, 1994q2, and 2002q2/2006q4, while the persistence breaks record around 1971q1, 1981q1, and 1991q4. Thus, our initial estimates lend strong support to the time-varying nature of inflation persistence, over the sample period.

Second, results based on median-unbiased-estimator (MUE) suggest that, during late-1970s through 1980s, CPI inflation seems to be very close to a unit root process, implying a high degree of persistence. However, since early-1990s, persistence has been falling, gradually; and currently, inflation is not well-characterised as a process with a unit root. Comparing the degree of persistence among some high inflation episodes, a clear distinction emerges, in that, during 1980 and 2008, inflation marks some record high levels (i.e., 26% in 1980q2 and 23% in 2008q2); yet, the persistence estimates record at near unit-root level (above 0.90) and 0.60, respectively. Overall, MUE results point towards significant changes in the inflation process and the degree of persistence, over time.

Third, the UC-SV estimates reveal some interesting characteristics of the nature of changes in the inflation process. Innovations to the inflation process seem to have effected changes differently over time, depending on relative importance of the trend and transitory components. For example, during mid-1970s through mid-1980s, the trend component becomes highly volatile than the transitory component, resulting long-lasting effects of inflation shocks (i.e., a higher degree of persistence). By contrast, in recent years, shocks that caused inflation rates to increase rapidly are of transitory nature, resulting only temporarily increases in inflation rates (yielding a lower degree of persistence). Thus, a key implication of the UC-SV results is that identifying the nature of the shock to the inflation process seems to offer some valuable information on the nature of future inflation movements. As such, bringing down inflation back to desired levels ought to involve monetary policy measures, targeting at avoiding the effects of adverse inflation shocks getting embedded into the trend component of the inflation process. In achieving that, a natural way forward may be to maintain a *credible anti-inflation policy* which is part and parcel in anchoring inflation expectations. In absence of such a policy, it is more likely that a shock that increases inflation today may result in de-anchoring of inflation expectations, and as a result, may have spiral effects through changes in the wage- and price-adjustments process (Cecchetti *et al*., 2007 and Mishkin, 2007). A key challenge for any Central Bank would be to avoid de-anchoring of inflation expectations, particularly, at times when there is continued upward pressure on the price level, failing which may result in transforming transitory shocks into more persistent movements in the inflation process.

Finally, results based on the TVP-VAR model with stochastic volatility reveal some interesting information on the nature of shocks that the economy has been experiencing during the post-1960 period. First of all, there is strong evidence of substantial time-variation in volatility of innovations to inflation, output growth and the policy variable. Overall, the volatility of shocks seems to be larger in the first-half of the sample than in the second-half. More importantly, volatility of shocks to both inflation and output growth has shown some greater moderation towards the end of the sample. Also, there is a clear pattern between the volatility of shocks to inflation and output growth, in that, both seem to move in the same direction most of the time.

The rest of the paper is structured as follows. Section 2 offers a discussion on the methodology adopted in the paper. Section 3 describes the dataset employed. Section 4 presents the results, which include standard least-squares estimates, median-unbiased-estimates; and Bayesian estimates of the UC-SV model and TVP-VAR model with stochastic volatility. Section 5 concludes.

2 METHODOLOGY

This section describes the methodology used in the paper to measure the degree of inflation persistence. First, we describe the procedure to obtain reduced-form evidence of inflation persistence based on a univariate AR process. Next, we describe the characterization of the UC-SV model and its implied measure of persistence. Finally, the TVP-VAR model with stochastic volatility is described.

2.1 REDUCED-FORM EVIDENCE OF INFLATION PERSISTENCE

Researchers use a variety of measures to obtain reduced-from evidence of inflation persistence. The underlying theme in most of the measures is that: inflation responds gradually to shocks, or it remains close to its recent history (i.e., inflation shows significant correlation with its own lags (Fuhrer, 2009)). In this context, univariate AR(p) models are widely used, because they offer several measures, namely: (a) the sum of lagged coefficients in the AR (p) model (where $p > 1$); (b) the largest AR root; (c) *half-life* of a shock to the inflation process; (d) the number of times inflation process crosses its mean etc. Generally these measures may deliver similar results (see Clark, 2003); yet, we focus on the first measure because it is the most cited in the literature (see for example, Cecchetti and Debelle, 2006; Marques, 2004; among others). Note, however, that all these measures may have limitations; while some are more likely to be relatively poor approximations to the 'true' degree of persistence, than others. For example, the largest AR root method may yield misleading results, because it ignores the other roots; for example, an AR(2) specification with roots 0.8 and 0.7 is more persistent than an AR(2) with roots 0.8 and 0.1, thus, ignoring other roots may result in poor approximation to the degree of persistence in the process Further, the *half-life* measure of persistence may tend to understate the persistence in the inflation process, if impulse response function is oscillating, and (even if it is monotonically decaying) profoundly convex to the origin (Pivetta and Reis, 2007).

We characterise the inflation process to follow a univariate AR process of order p:

$$\pi_t = \alpha + \phi_1 \pi_{t-1} + \phi_2 \pi_{t-2} + \cdots + \phi_p \pi_{t-p} + \eta_t, \tag{1}$$

where π_t is inflation in period t, α is constant, η_t is serially uncorrelated with mean zero and constant variance, and ϕ_j are parameters to be estimated. In this model, persistence is given by the sum of AR coefficients, i.e., $\sum_{j=1}^{p} \phi_j$, which implies the cumulative response of inflation to shock η_t. Rearranging equation (1), we obtain a measure of persistence, i.e., the sum of autoregressive coefficients (Andrews and Chen, 1994):

$$\pi_t = \alpha + \rho \pi_{t-1} + \sum_{j=1}^{p-1} \beta_j \Delta\pi_{t-1} + \eta_t, \tag{2}$$

where $\rho = \sum_{j=1}^{p} \phi_j$ is the sum of AR coefficients and $\beta_j = -\sum_{i=1+j}^{p} \phi_i$.

Before estimating the degree of persistence, we need to allow for possible shifts in the mean inflation. Our approach for testing mean shifts is motivated by Ng and Vogelsang (2002) and Bataa *et al*. (2007), in that, breaks are estimated using the following model (see also Batini, 2006):

$$\pi_t = \mu_{t,j} + \eta_t, \tag{3}$$

where $\mu_{t,j}$ implies a time-varying mean inflation, j indicates each period during which mean inflation is stable; and η_t has zero mean and covariance matrix Σ_j. Thus, once mean shifts are identified, we obtain a mean removed inflation series by subtracting the time-varying mean from the actual inflation series, thus yielding the model in equation (2) as follows:

$$\pi_t = \rho\pi_{t-1} + \sum_{j=1}^{p-1} \beta_j \, \Delta\pi_{t-1} + \eta_t \tag{4}$$

where the parameter ρ is our preferred measure of persistence. To select the lag structure, we use the AIC information criterion, which suggests a maximum lag order of $p = 5$ (note that the SIC information criterion also implies a similar lag structure).

2.2 MEDIAN-UNBIASED-ESTIMATES OF PERSISTENCE

For median-unbiased-estimates of persistence, we employ the model in equation (2), and obtain estimates of ρ using rolling-regressions method following the procedure described in Hansen, (1999). The 90 percent confidence intervals are produced by simulating the sampling distribution of t-statistic; $t = (\hat{\rho} - \rho)/se(\hat{\rho})$, where $\hat{\rho}$ is least squares estimate of ρ, and $se(\hat{\rho})$ is the estimated standard error. For rolling-regressions, an appropriate window-width needs to be specified, so we use two alternative window-widths, namely, 12- and 15-years, which provide a long enough samples to assess persistence (i.e., 48 and 60 quarters, respectively).[8]

[8] It is standard in the literature to consider rolling regression window-widths ranging from 10- to 15-years (see Pivetta and Reis, 2007; Fuhrer, 2009; among others). In our study, it turns out that results are robust across alternative choices of windows, one noticeable difference is, however, that confidence intervals get a bit wider in shorter samples, as one would expect.

2.3 UNOBSERVED COMPONENTS-STOCHASTIC VOLATILITY (UC-SV) MODEL

As Cogley and Sbordone (2008) describe, the degree of inflation persistence may vary substantially over time due to a time-varying trend inflation. Thus, in order to measure and interpret persistence correctly, one may need to account for time-variation in the trend inflation. In this context the unobserved components-stochastic volatility (UC-SV) model comes in handy (see Stock and Watson, 2007).[9] The idea behind the UC-SV models is straightforward, in that, inflation process is characterised as the sum of a random walk component (τ_t) which represents the trend inflation, and a transitory disturbance term (η_t). As the relative variance of disturbances to these components changes over time, the relative importance of the trend and transitory components may change, as well.

Thus, the UC-SV model takes the following form:

$$\pi_t = \tau_t + \eta_t, \quad \text{where } \eta_t = \sigma_{\eta,t}\varsigma_{\eta,t},$$
$$\tau_t = \tau_{t-1} + \varepsilon_t, \text{ where } \varepsilon_t = \sigma_{\varepsilon,t}\varsigma_{\varepsilon,t}, \tag{5}$$

where $\sigma_t = (\sigma_{\eta,t}, \sigma_{\varepsilon,t})$ is time t standard deviation of the process. The logarithms of variances of innovations are specified as independent random walks:

$$\ln \sigma_{\eta,t}^2 = \ln \sigma_{\eta,t-1}^2 + \nu_{\eta,t},$$
$$\ln \sigma_{\varepsilon,t}^2 = \ln \sigma_{\varepsilon,t-1}^2 + \nu_{\varepsilon,t}, \tag{6}$$

where $\varsigma_t = (\varsigma_{\eta,t}, \varsigma_{\varepsilon,t})$ is *i.i.d.* $N(0, I_2)$, and $\nu_t = (\nu_{\eta,t}, \nu_{\varepsilon,t})$ is *i.i.d.* $N(0, \chi I_2)$, in that, ς_t and ν_t are independently distributed, and χ is a scalar parameter, which controls the smoothness of the stochastic volatility process.

[9] The idea of unobserved-components (UC) models is not entirely new and dates back to Milton Friedman's analysis on permanent income hypothesis in late-1950s (see also Muth, 1960). However, as described in Stock and Watson (2007), UC models suffer from a key drawback because they cannot account for stochastic volatility in innovations to the inflation process. Thus, they introduce a generalization of the UC models, in that, variance of disturbances to these components evolves randomly over time.

In this set up, the variances of $\nu_{\eta,t}$ and $\nu_{\varepsilon,t}$ determine the volatility of $\sigma^2_{\eta,t}$ and $\sigma^2_{\varepsilon,t}$. If, for example, variance of $\nu_{\eta,t}$ is zero, then $\ln\sigma^2_{\eta,t} = \ln\sigma^2_{\eta,t-1}$, which implies no stochastic volatility in η_t. As described in Cecchetti *et al.* (2007), if variance of $\nu_{\eta,t}$ is large, then, $\sigma^2_{\eta,t}$ may show large period-by-period proportional changes. To allow for such a possibility, one may need to model $\nu_{\eta,t}$ as a mixture of two normal distribution, i.e., $\nu_{\eta,t} \sim N(0,\chi_1)$ with some probability , and $\nu_{\eta,t} \sim N(0,\chi_2)$ with a probability of $(1-p)$. Thus, if p is larger and $\chi_1 < \chi_2$, then, most draws of $\nu_{\eta,t}$ are from a low variance distribution, with some occasional draws from a large variance distribution.

As depicted in Figure 1, our inflation data shows some large occasional jumps, so, to model such behaviour, we draw disturbances $\nu_t = (\nu_{\eta,t}, \nu_{\varepsilon,t})$ from a mixture of normal distributions, where $\nu_{\eta,t} \sim N(0,0.2I)$ with probability 0.98 and $\nu_{\eta,t} \sim N(0,0.8I)$ with probability 0.02, and the same is applied to $\nu_{\varepsilon,t}$. The model is estimated using the Markov-Chain-Monte-Carlo (MCMC) algorithm, as described in Stock and Watson (2007). Our simulations are based on 10,000 iterations discarding the first 500 for convergence. For robustness, we experiment with alternative parameter values for the mixture innovations and alternative number of draws.

2.4 PERSISTENCE IN THE UC-SV MODEL

Rearranging the model in equation (5) yields: $\Delta\pi_t = \varepsilon_t + (1-L)\eta_t$, which is equivalent to a first difference of a random walk plus noise model. Accordingly, by computing variance and covariance of the change in inflation, a measure of persistence can be obtained, i.e., the variance of $\Delta\pi_t$ is given by $E\left[\left(\Delta\pi_t - E(\Delta\pi_t)\right)^2\right] = E[(\varepsilon_t + (1-L)\eta_t)^2] = \sigma^2_\varepsilon + 2\sigma^2_\eta$, and the covariance between current and last period $\Delta\pi_t$ is given by $E[(\varepsilon_t + (1-L)\eta_t)(\varepsilon_{t-1} + (1-L)\eta_{t-1})] = -\sigma^2_\eta$, and the resulting persistence coefficient is given by:

$$\rho_{\Delta\pi} = \frac{cov(\Delta\pi_t, \Delta\pi_{t-1})}{var(\Delta\pi_t)} = \frac{-\sigma^2_{\eta,t}}{2\sigma^2_{\eta,t} + \sigma^2_{\varepsilon,t}} \cong [-0.5,0]. \quad (7)$$

Equation (7) implies that, if variance and autocovariance of the change in inflation are constant, the correlation coefficient (persistence) may be time-invariant. By contrast, if variances of ε_t and η_t change over time, the correlation coefficient may reflect these changes. Thus, a key prediction of the UC-SV model in terms of inflation persistence may be that, if relative importance of volatility in trend component is more dominant, then inflation process may tend towards a pure random-walk, implying a higher degree of persistence. On the other hand, if relative importance of volatility in the transitory component dominates, inflation process may exhibit a lower degree of persistence.

2.5 MULTIVARIATE MODEL

The multivariate model used in this study falls into the strand of literature based on time-varying parameter vector-autoregressive (TVP-VAR) models with stochastic volatility. We allow the VAR coefficients, as well as the entire variance-covariance matrix of innovations to change over time (see Primiceri, 2005). As described above, the UC-SV model estimates the variance of innovations to the inflation process in a univariate context; so, the main purpose of this exercise is to extend the analysis to a multivariate context, as such, to obtain estimates of variance of inflation shocks, given other macroeconomic variables of interest. In doing so, we may be able to examine any link between the variance of shocks to the inflation process and the variance of shocks to other macroeconomic variables.

The characterisation of the model is as follows, in that, the measurement equation is:

$$y_t = X_t'\theta_t + u_t, \tag{8}$$

where y_t is a vector of endogenous variables, X_t includes a constant plus lags of y_t , and θ_t is a vector of VAR parameters, and u_t are heteroscedastic unobservable shocks with variance covariance matrix Ω_t. Following Primiceri (2005), a triangular reduction of the measurement error covariance is used, such that, $A_t\Omega_t A_t' = \Sigma_t\Sigma_t'$, where Σ_t is a diagonal matrix with diagonal elements $\sigma_{j,t}$ for *j*=1,…*p* , and A_t is the lower triangular matrix:

$$A_t = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ \alpha_{21,t} & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ \alpha_{n1,t} & \cdots & \alpha_{nn-1,t} & 1 \end{bmatrix}.$$

Thus, the errors in the measurement equation are given by $A_t^{-1}\Sigma_t\varepsilon_{t,}$ where $\varepsilon_{t,}$ is assumed to be $N(0, I_n)$. Further, the dynamics of the model's time-varying coefficients are specified as follows:

$$\theta_t = \theta_{t-1} + \nu_{t,}$$

$$\log \sigma_t = \log \sigma_{t-1} + \eta_{t,}$$
$$\alpha_t = \alpha_{t-1} + \zeta_{t,}$$

where ν_t are independent $N(0, Q_t)$ random vectors for t,..., T, and η_t is $N(0, W)$, and is independent over t, and of u_t and ν_t. The evolution of A_t is characterised by $\zeta_t \sim N(0, C)$ and is independent over t, and η_t, u_t and ν_t.

The model is estimated using the Markov-Chain-Monte-Carlo (MCMC) algorithm described in Primiceri (2005-Appendix A), and the priors as described in the *Section 4.1* in Primiceri (2005). We choose the order of the dependent variables as follows: inflation, GDP growth rate, and monetary growth rate/interest rate. Thus, the identifying assumptions made are: as for the policy block, the shock to the policy variable has no immediate effects of non-policy block variables (see Bernanke and Mihov, 1998, Primiceri, 2005, among others). As for the non-policy block, we assume that the shock to the GDP growth has no immediate effect on inflation. As discussed by Primiceri (2005) and Koop *et al.* (2009), the ordering of the variables in the non-policy block could affect inference on the covariance matrix, given the lower-triangular structure of A_t. Therefore, we experiment with alternative ordering in the non-policy block, i.e., assuming the shock to the inflation has no immediate effect on GDP growth. It turns out that, the empirical results are very similar to this alternative ordering, given our dataset.

We use only one policy variable at a time for parsimony of the model. Note, however, that a single policy variable may be little difficult to pin down for the entire sample period, given the changes in the monetary policy framework in Sri Lanka over time. Also, the policy rates used by the Central Bank (i.e., the repurchase rate and reverse repurchase rate) are not available for the full-sample period. We choose the growth rate of reserve money as one of proxies for the policy variable, because, the reserve money is the operating target of the current monetary policy set up (the monetary targeting programme). Alternatively, as a proxy for policy interest rates (which are used to achieve the set goals in the monetary programme), we use the 'interbank call money market rate' which is within the lower and upper bounds of the corridor set by policy interest rates. [10]

3 THE DATA

[10] For robustness, we use exchange rate changes in the policy block, however, our conclusions are not affected by this.

We use quarterly data (seasonally adjusted) from 1960q1-2009q4. Our main data source is the IMF International Financial Statistics (IFS) database, and for some missing data, we use Central Bank's annual reports and other publications such as monthly bulletins.[11] We define the variables of inflation, real GDP growth, and reserve money growth at an annual rate, for example, inflation is defined as: $\pi_t = \ln(P_t/P_{t-4})$, where P_t is the price level. Because of the length of the sample and its frequency, we are restricted to use only the Consumer Prices Index (CPI) data for our inflation measure. The alternative candidate would be the GDP deflator index which is available only in annual frequency for the entire sample. As for the real GDP data, we construct a real GDP series by deflating the nominal GDP series (annual) by the GDP deflator index (annual), and then interpolate it using the Goldstein and Khan (1976) method to obtain a quarterly series (seasonally adjusted). Thus, because of any possible measurement error in quarterly real GDP series, one ought to be careful in interpreting the results. The reserve money data are available in quarterly frequency for the full sample. Quarterly data on the 'interbank call money market rates', is available only from 1978q1 in the IFS database, so we extend this series backward using Central Bank's publications. Figure 2 plots the real GDP growth rates, reserve money growth rates, and interbank call money rates.

4 RESULTS

The results reported in this paper fall into three groups. First, reduced-form evidence of inflation persistence, based on the least-squares estimator and the median-unbiased-estimator. Second, results of the UC-SV model, comprising of the estimates of standard-deviations of innovations to the trend and transitory components of the inflation process, along with the estimates of inflation persistence implied in the UC-SV model. Finally, results based on the TVP-VAR model with stochastic volatility, where we describe the estimates of standard deviations of innovations to the inflation equation, output growth equation, and policy variable equation.

4.1 SHIFTS IN MEAN INFLATION

[11] The IFS reference for each data series is as follows: (i) 64...ZF CPI: COLOMBO 455 MNUAL WRKRFAM (Units: Index Number); (ii) 99BIPZF GDP DEFLATOR (2005=100) (Units: Index Number); (iii) 99B..ZF GROSS DOMESTIC PRODUCT (GDP) (Units: National Currency) (Scale: Millions); (iv) 14...ZF RESERVE MONEY (Units: National Currency) (Scale: Millions); and (v) 60B..ZF INTERBANK CALL LOANS (Units: Percent per Annum).

Accounting for possible mean shifts is imperative to obtain accurate estimates of persistence. Instead of using an arbitrarily imposed number of mean shifts as in the case of traditional breakpoint tests, we use the latest structural breakpoint tests which allow the data to detect the exact number of breaks. This section reports results based on two such procedures, namely, Andrews and Ploberger (1994, hereafter, AP test) and Qu and Perron (2007, hereafter, QP test).

Before proceeding, some points worth highlighting on the procedure adopted in deriving the breakpoint tests. Because these tests detect only one break at a time, we carry out the tests iteratively, i.e., if the null of no structural break is rejected, we split the sample in correspondence to the estimated breakdate, and repeat the same, until the test fails to reject the null of parameter stability. On making the choice between rejecting or accepting the null, we use the *exponential-Wald F*-statistic (and the approximated asymptotic *p*-values based on Hansen, 1997). Following the standard practice, we assume that a break did not occur within the first and the last 15 percent of the sample. As for the QP tests, the procedure is somewhat different, because QP tests can detect multiple breaks simultaneously. There, we use the *sequential* testing procedure, in that, first, we specify a maximum number of breaks (with an appropriate trimming parameter), and then, test down for the exact numer of breaks. In doing so, all insignificant breaks are omitted until all breaks are rendered statistically significant at conventional levels. In implementing QP tests, it is important to select an appropriate trimming parameter (λ) for a given maximum number of breaks (*M*), because, these parameters are crucial in determining the size and the power of the test statistic, in that, a smaller λ would lower the correct size of the test, while a larger λ would lower the power of the test. As a practical guidance, following combinations are suggested (see Bai and Perron, 2003): for a maximum number of breaks of 8, 5, 3, and 2, the trimming parameter to be used is λ = 0.10, 0.15, 0.20 and 0.25, respectively. Given that we use quarterly data with 200 observations, we start with a maximum of 5 breaks with λ = 0.15, and test down for the exact number of breaks. QP breakpoint test results are reported with 90 percent confidence intervals.

Table 1 reports the results for shifts in the mean inflation, and least-squares estimates of unconditional mean across the identified breakdates. Figure 3 depicts these mean shifts along with actual inflation data, clearly showing the identified breakdates capturing well the overall pattern of actual inflation series. The results in Table 1 lend strong support to the claim that inflation processes has shown some significant parameter instability over the sample period. Both testing procedures detect five breakpoints which are statistically significant, and four of them are almost identical across the testing procedures (they occur in 1967q3, 1978q2, 1986q2, and 1994q2, based on QP tests). Also, there is some evidence of a possible break around 2002q2 (QP tests) or 2006q4 (AP tests).[12] Of these breakpoints, the first three, which are around 1967, 1978, and 1986 are highly significant (at 1 percent level as reported by AP tests, and tighter confidence intervals reported by QP tests). The other two breaks (i.e., 1994 and 2006 as given by AP tests) are significant at 5 and 10 percent levels, respectively, while the breakpoints detected by QP tests (i.e., around 1994 and 2002) involve somewhat wider confidence intervals.

It would be interesting see whether these breakdates match with any readily identifiable macroeconomic events. It is clearly evident that the breakpoint detected in 1978q2, may be a direct result of the surge in commodity prices, following the introduction of open economic policies by the end of 1977. As Table 1 reports, mean inflation jumps to a significantly high level of about 15 percent following this break, from about 6 percent in the preceding period. As for the other breakpoints, there may be a combination of several factors that trigger changes in the inflation process due to changes in the aggregate demand and supply conditions such as changes in oil prices, changes in the policy framework, escalation of domestic war from time to time (say, around mid-1990s and mid-2000s), significant changes in weather pattern etc. Note that on the changes in monetary policy framework, two key events may be worth highlighting, namely, introduction of more active open market operations in October 1993, and introduction of floating exchange rates in January 2001. However, a more detailed investigation needs to be carried out to pin down exact forces behind these mean shifts (and it is beyond the scope of this paper, because our primary purpose is to document evidence on the degree of inflation persistence).

4.2 ESTIMATES OF INFLATION PERSISTENCE

Table 2 reports the estimated breakdates and degree inflation persistence, allowing for the mean shifts. There is strong evidence of time-variation in the persistence parameter, as the QP tests detect three statistically significant breakpoints (with fairly tight confidence intervals). They occur around 1971q1, 1981q1, and 1991q4. It turns out, however, that the breakdates found in AP tests are rendered statistically insignificant, hence, not reported. As shown in the Table 2, persistence has been relatively low at the beginning of the sample (around 0.42 during 1960q1-

[12] Obviously, the QP tests may not detect breaks towards the very end of the sample because of trimming of 15 percent based on the full-sample, while AP tests may detect breaks due to repartition procedure based on sub-samples.

1970q4); however, persistence shows a dramatic upward shift during 1971q1-1980q4, recording at about 0.77, and even higher during 1981q1-1991q3, marking around 0.89. During 1991q4-2009q4, persistence falls from the very high levels to a moderate level of around 0.60. Overall, results point towards significant parameter instability in the degree of persistence, in that, inflation has been highly persistent during 1970s and 1980s, and there appears to be a favourable downward shift towards the end of the sample. Yet, at present, inflation persistence may not be marked as 'low', because the recent inflation dynamics mark some moderately high degree of persistence.

The evidence documented so far, seems to question the notion that inflation persistence is structural and needs to be 'hardwired' into the deep structure of the economy (see also Benati, 2008). On balance, our initial evidence lends strong support to the hypothesis that inflation persistence has been time-varying during the sample period. This raises the question as to what factors may have effected these changes. We attempt to provide an answer, when we discuss results based on the UC-SV model and the TVP-VAR model. Before that, we intend to address a potential drawback of the least-squares estimates i.e., the estimator tends to be biased downward as the persistence coefficient approaches unity. A natural way forward would be to use the median-unbiased-estimator to obtain persistence estimates; and we describe such results in the next section.

4.3 PERSISTENCE ESTIMATES BASED ON MEDIAN-UNBIASED-ESTIMATOR (MUE)

Figure 4 plots a time-profile of persistence estimates (along with 90 percent confidence interval bands), as measured by the sum of autoregressive coefficients in an AR(6) inflation process. The estimates are based on rolling regressions with a 15-year window-sample.[13] Because the MUE estimator uses the first 15-years of data, the results start from 1976q1. As the Figure shows, persistence has been significantly high from the beginning of the sample through mid-1990s. To be precise, there is a sharp upward shift during late-1970s, since then, estimates hover around 0.90, on average, throughout early-1990s. However, since mid-1990s, persistence starts falling significantly, and marks the lowest about 0.55 by mid-2000s. Towards the end of the sample, persistence seems to pick up for a while, before falling to a moderately high level of about 0.60.

[13] The results are obtained using median-unbiased-estimator based on Hansen (1999) 'grid bootstrap' procedure with 2,000 replications. We replicated the results with 12-year window samples and obtained qualitatively similar results, albeit with some wider confidence intervals.

A key point to note is that there is a marked difference in the behaviour of persistence parameter across some comparable high inflation episodes during the sample period, i.e., around late-1970s/early-1980s, early-1990s, and late-2000s. In particular, a stark contrast exists between the first and the last period, during which inflation rates mark record high levels (i.e., 26% in 1980q2, and 23% in 2008q2, respectively); yet, the estimates of persistence largely differ across these periods. More specifically, persistence increases dramatically around late-1970s, to a near unit-root level, and remains there for about a decade or so. By contrast, during the recent years, despite the increase of inflation rates to an almost similar level of late-1970s, persistence increases only mildly in relative terms (i.e., to about 0.70). More importantly, the increase in persistence in recent years is short-lived, because it falls rather quickly to a moderately high level of about 0.60 by the end of the sample. Note that the recent inflation dynamics are quite unprecedented, in that, inflation rates increase and fall dramatically within a very shorter period of time (i.e., an increase to a staggering 23% in 2008q2 followed by a remarkable decline to a record low level of 1% by 2009q3). Overall, the results suggest that there has been noticeable time-variation in inflation's reduced-form persistence over time, and in particular, CPI inflation seems to be very close to a unit-root process during late-1970s through 1980s, while it is not currently well-characterised as a process with a unit root. From the empirical evidence documented so far, it becomes clearer that both mean and persistence parameters are timevarying, thus, lending strong support to our choice of the Bayesian approach to investigate the issue further. We discuss the results in the next section.

4.4 RESULTS BASED ON UC-SV MODEL

As shown above, there is a strong case for modelling time-variation in the mean inflation and persistence parameter in the CPI inflation process. In this context, the UC-SV framework may come in handy because it treats the model parameters as being random and time-varying. To be more precise, in the UC-SV framework, inflation is modelled as the sum of two stochastic components, namely, a random walk component and a transitory component, in that, the former may capture any time-variation in the trend inflation, while the latter may capture any deviation of actual inflation from that trend. A key advantage of this model is that it allows for the possibility of time-varying variance (stochastic volatility) of innovations to these two components. Given our dataset, it seems reasonable to expect substantial changes in volatility in the inflation process (see Figure 1). In estimating the model, we draw disturbances to the trend and transitory components from a mixture of normal distributions, thus, allowing for the possibility of infrequent large changes to the inflation process (Cecchetti et al., 2007).

We derive three sets of results from the UC-SV model.[14] First, we report smoothed estimates of standard deviations of disturbances to the trend and transitory components (Figure 5); second, we report smoothed estimates of the trend component, which tracks the time-varying trend inflation (Figure 6); and finally, we report estimates of time-varying inflation persistence, as implied in the UC-SV model (Figure 7).

The top panel of Figure 5 plots the estimated standard deviations of innovations to the trend component (marked as 'trend-volatility'), while the bottom panel shows estimates of standard deviations of innovations to the transitory component (marked as 'transitory-volatility'). A clear distinction emerges among these estimates. The trend-volatility is relatively low from the beginning of the sample through mid-1970s, at which point it increases significantly and stays there through mid-1980s. However, since mid-1980s, trend-volatility starts falling, and drops to very low levels by mid-1990s. More interestingly, since mid-1990s, trend-volatility tends to stay at lower levels throughout the remainder of the sample, despite the actual inflation rates show some significant changes (note, however, that there is some evidence of wider confidence intervals). By contrast, the transitory-volatility exhibits an opposite behaviour to trend volatility, in that, it remains low from mid-1960s through early-1990s (during which trend-volatility stays high), while it marks a significant increase during mid-1990s, and then shows a gradual decline through mid-2005. Interestingly, there is a significant upward shift in transitory volatility towards the end of the sample, suggesting the effects of recent shocks to the inflation process seem to have been of transitory nature.

What does this evidence tell us about the time-varying nature of the inflation process? Two key points worth highlighting. First, changes in the inflation process seem to be well-characterised by changes in volatility of innovations to the trend and transitory components. Second and more importantly, depending on the relative importance of the volatility of each component, shocks to

[14] Results are produced in GAUSS 6.0, using an appropriately amended version of Prof. Mark Watson's code, with 10,000 draws of the Markov-Chain-Monte-Carlo (MCMC) procedure. We prefer smoothed estimates to filtered estimates, as the former may be thought of as the best estimate of what happened in the past from today's vantage point; while the latter may refer to real-time estimates. We draw disturbances of $\nu_t = (\nu_{\eta,t}, \nu_{\varepsilon,t})$from a mixture of normal distributions, with $\nu_{\eta,t} \sim N(0, 0.2I)$ with probability 0.98 and $\nu_{\varepsilon,t} \sim N(0, 0.8I)$ with probability 0.02, and the same applies to [illegible]. Note that qualitatively similar results are obtained for alternative parameter values and number of draws.

the inflation process may effect changes *differently*. For example, when a shock hits the trend component, the effects on inflation tend to be long-lasting (as it has been the case during mid-1970s through mid-1980s; while, in contrast, a transitory shock effects only a temporary rise in inflation, in that, inflation reverts back fairly quickly to pre-shock levels (which seems to be the case in the recent years). Thus, identifying the nature of the shock may offer some valuable information on future movements of the inflation process. Put differently, by avoiding the effects of a shock getting embedded into the trend component may be crucial in the Central Bank's endeavour to bring inflation down to desired levels. On the possibility, literature points towards a key prerequisite (among other things) i.e., anchoring of inflation expectations through *credible* policies (see Cecchetti *et al*., 2007; Mishkin, 2007; among others). In absence of *credible* policies, a shock that increases inflation today may result in de-anchoring of inflation expectations which may have spiral effects through changes in the wage- and price-adjustments process. This line of explanation seems to be core within the UC-SV framework, because inflation expectations and trend inflation are closely linked in this model, in that, expected inflation may well be approximated by the current value of trend inflation:

$$E_t\pi_{t+h} = E_t\tau_t = \tau_{t/t,}$$

where $\tau_{t/t}$ is the filtered value of τ_t and h is the forecast horizon (see Cecchetti *et al*., 2007). This result comes from the feature that expected value of a random walk process is given by its current trend value.[15] Further, as Mishkin (2007) describes "de-anchoring of inflation expectations would surely lead to trend inflation becoming unanchored, whereas an anchoring of inflation expectations at a particular level would necessarily lead to a stabilization of trend inflation and hence a decline in inflation persistence" (p.9). Thus, following this literature, we describe next the estimates of trend inflation and inflation persistence implied in the UC-SV model.

4.5 ESTIMATES OF TIME-VARYING TREND INFLATION

Figure 6 plots the estimates of trend inflation in the CPI inflation series. A key observation to make is that the CPI inflation trend shows a substantial time-variation from mid-1960s through

[15] However, based on Granger causality tests, Cecchetti *et al.* (2007) find that trend inflation significantly influence (survey based) inflation expectations than the reverse causality. Note in a related study, Cecchetti and Debelle (2006) describe that changes in inflation expectations seem to be the most likely candidate behind shifts in mean inflation. In particular, they find evidence that breaks in inflation expectations slightly precede breaks in mean inflation.

early-1990s; and since then, it shows some remarkable stability. It is clearly evident that trend inflation shows a dramatic upward shift around late-1970s, coinciding with the record high inflation rates around that time. By contrast, since early-1990s, trend inflation declines to moderately high levels, and more importantly, it becomes quite stable at that level, despite the actual inflation exhibits significant swings, particularly, during the recent years. Note that the trend inflation becoming anchored around a moderately high level may not be good news at all, particularly, when inflation rates are showing a declining trend; however, that stability in the trend inflation during the recent year, has exhibited some resilience amidst of huge upward pressure on the price level. As Figure 6 clearly shows trend inflation increases only mildly around 2008, before it starts falling rather quickly by 2009. By contrast, the trend inflation in 1970s and 1980s follows the actual inflation very closely.

There may be several explanations to this substantial time-variation in trend inflation. Potential candidates may include changes in the monetary policy framework (monetary targeting/ exchange rate policy), changes in the driving process of inflation (deviations of output or unemployment from the long-run trend levels), observed supply-side shocks (e.g., oil price shocks), changes in trade and financial openness, changes in labour productivity etc. As described above, the UC-SV model implies that changes in the inflation expectations formation process may also be crucial in determining the trend-inflation behaviour. According to Mishkin (2007) "[w]hen inflation expectations are anchored, the trend component of inflation will also be anchored and will thus fluctuate less" (p.23). However, in general equilibrium, all these factors may be inter-linked, and affect the inflation process in varying degrees. As such, identifying the sources of inflation fluctuations remains a challenge to a larger extent. Our results based on the multivariate model, as will be described later, may shed some light on that (in terms of volatility in other macroeconomic variables as well). Before that, as our primary purpose of this study is to document evidence on inflation persistence, we describe next the persistence estimates from the UC-SV model.

4.6 Estimates of Time-varying Persistence

As described in the methodology section, we derive a measure of persistence within the UC-SV model in terms of the correlation coefficient of the change in inflation. By construction, the estimates range from 0 to -0.50, in that, a value closer to zero implies a high degree of persistence and a value closer to -0.50 implies a low degree of persistence. Figure 7 plots the results. As expected, there is significant time-variation in the estimates over the sample period, showing a hump-shaped pattern. Persistence tends to be low at the beginning of the sample, and increases to very high levels from 1970s through 1980s, reaffirming the evidence documented so far. Since early-1990s, persistence drops dramatically, and tends to stay at very low levels throughout the remainder of the sample. Interestingly, the low persistence estimates towards the end of the sample are clearly indicative of the rise and fall of inflation rates within a very shorter period. More specifically, because the transitory component of inflation is responsible for a larger proportion of recent inflation fluctuations, persistence estimates do not rise as much.

To sum up the key findings from the UC-SV estimates: (a) volatility of disturbances to the inflation process shows substantial variation over time; (b) the magnitude and persistence of these variations depend on relative importance of trend and transitory components at a given time; (c) trend inflation shows substantial variation over time, and the timing of some changes seem to coincide with significant macroeconomic events such as the increase of price levels following the introduction of open economic policies etc; and finally, (d) there is strong evidence of volatility in inflation persistence, in that, during 1970s through 1980s persistence has been significantly high; while, since early-1990s, it has been low. The results based on the UC-SV model may seem useful in explaining why in certain periods, 'high' inflation rates are too slow to recede, than in other times. For example, high inflation rates observed during 1970s and 1980s seem to have taken a longer time to fall back into average levels, where as high inflation rates observed during recent years fall rather quickly into the trend inflation level. As described, during 1970s and 1980s, high inflation rates seem to have been a direct result of shocks to the trend inflation, while during recent years, shifts in inflation rates seem to have been caused by transitory shocks.

Despite more appealing characteristics of the UC-SV model, the estimates of inflation volatility are based on a univariate inflation process, which may not capture any interrelationships with the volatility of other macroeconomic variables. In the next section, we describe the volatility in the inflation process measured within a multivariate model with stochastic volatility.

4.7 Results from TVP-VAR Model with Stochastic Volatility

The purpose of the multivariate model is to gauge any inter-relationships between the volatility in the inflation process and volatility in other variables in the model. In doing so, we may be able to better understand the nature and magnitude of shocks that the economy has been experiencing over time. The model includes three variables, namely, inflation, output growth, and a policy variable. While inflation and output growth represent the non-policy block; the policy block includes reserve money growth or short term interest rates. The choice of a fewer number of variables is mainly down to constraining the number of parameters in the model (see Primiceri, 2005; and Koop at al., 2009, among others). For estimation we use 2 lags, and the simulations are based on 20,000 iterations of the Gibbs sampler, discarding the first 5,000 for convergence. To calibrate the prior distributions, we use the first 32 observations (8 years), and all priors take the forms as described in Primiceri (2005, Section 4.1). Note, however, that the results reported below are robust across alternative prior specifications.

The panels in Figure 8 plot the point estimates of standard deviations of innovations to the (a) inflation equation, (b) output growth equation, and (c) policy variable equation, respectively.[16] We report two sets of estimates in each panel, based on the alternative policy variables, namely, reserve money growth and short term interest rates. Figure 8(A) clearly depicts several episodes of high inflation volatility, i.e., around early- and latter- parts of 1970s, mid-1990s and early-2000s. An interesting observation to make is that the volatility of inflation shocks during the recent high inflation episode seems to be significantly lower than the volatility of inflation shocks during any other high inflation periods. Figure 8(B) depicts the volatility of shocks to output growth, showing some clearly identifiable spikes around early- and latter- parts of 1970s, mid-1990s (relatively mild, though) and early-2000s. These high episodes of output volatility seem to correspond well with the periods of substantial drops in output growth over time (observe the output growth rates in Figure 2(A)). There is some clear evidence of moderate output volatility towards the end of the sample. Also, observe that there is a considerable degree of resemblance of the movements between volatility of shocks to the inflation and output growth equations. In particular, during late-1970s, late-1990s, and mid-2000s, as output volatility moderates, inflation volatility also tends to moderate, almost at the same time.

The bottom panel of Figure 8 shows the volatility of innovations to the policy variable. A clear distinction emerges between the volatility of reserve money growth shocks and interest rate shocks, in that, the former is significantly higher than the latter. The interest rate volatility has

[16] The reported estimates are the posterior means; and, for clarity in the Figure, we do not report error bands (e.g., 16th and 84th percentile bands, which under normality, correspond to the intervals of a one-standard-deviation). Note, however, that the confidence intervals do indicate some degree of imprecision, but the reported changes in the volatility are still relatively large.

been significantly low till early-1980s, during which the use of interest rate as a monetary policy instrument has been minimal. However, during 1990s, interest rate volatility seems to be relatively larger. Note that this period marks some significant changes in the monetary policy set up, including the measures taken to closely monitor the 'interbank call money rate', following the introduction of repurchase facility in 1993, and reverse repurchase facility in 1995. Since early-2000s, interest rate volatility shows some degree of moderation. As for the volatility of reserve money growth, it has been highly volatile during 1970s, and has shown some degree of moderation during 1980s through early-1990s. During the last decade or so, two observations stand out: one in 1997 and the other in 2009, both marking a significant increase in the volatility of shocks to reserve money growth, and they seem to correspond well with the significant drops in money growth rates around these years (observe the reserve money growth rates depicted in Figure 2(B)).

To sum up the results from the multivariate model: (a) there is strong evidence of substantial time-variation in volatility of all equations, thus, making a strong case for the time-varying parameter models; (b) there is a clear pattern emerging between the innovation variance of inflation and output growth equations, in that, both seem to covary positively, most of the time; (c) importantly, innovation variance to both inflation and output growth has shown some degree of moderation towards the end of the sample; and finally, (d) innovation variance to money growth has been much more volatile than innovation variance to interest rate.

5 CONCLUSION

The goal of this study is to examine a key property of the inflation process, namely, the degree of inflation persistence, using Sri Lankan data from 1960q1-2009q4. We employ several modelling and estimating techniques, which require classical and Bayesian estimation procedures. In the classical estimates, our preferred measure of persistence is the sum of AR coefficients (Andrews and Chen, 1994), estimated via standard least-squares-estimator and median-unbiased-estimator with Hansen (1999) grid-bootstrap procedure. We employ latest econometrics on structural breakpoint tests (Qu and Perron, 2007) to examine parameter instability in the inflation process, and in particular, to obtain more accurate estimates of persistence, allowing for shifts in the mean inflation (Perron, 1990; Hansen, 2001). Also, we employ Bayesian estimation techniques to obtain time-varying-parameter estimates of persistence in the context of a UC-SV model (Stock and Watson, 2007), in that, inflation is modelled as the sum of two components, namely trend and transitory component. In this context, persistence estimates are based on the relative variance of innovations to the trend and transitory components in the inflation process (Cecchetti *et al*., 2007). Finally, we employ a TVP-VAR model with stochastic volatility (Primiceri, 2005; Koop *et al*., 2009), with the view to examine the evidence of time-varying nature of the inflation process in a multivariate context, vis-à vis the univariate estimates in the UC-SV framework.

Weighing all the evidence from alternative modelling and estimation techniques leads us to the conclusion that CPI inflation has been highly persistent during 1970s and 1980s, and may be characterised as a process with a unit root during this period. However, since early-1990s, inflation process seems to have changed significantly, in that, persistence has been falling to moderate levels towards the end of the sample period. The UC-SV estimates reveal some interesting characteristics of the inflation process, in that, during mid-1970s through mid-1980s, inflation dynamics are mainly driven by shocks to the trend component, implying long-lasting effects of shocks to the inflation process, and consequently a high degree of persistence. By contrast, during recent years, transitory component drives most of the inflation dynamics and, as a result, delivering relatively low persistence. The results from the TVP-VAR model reinforce the findings of the UC-SV model, in particular, they show a clear pattern between the volatility of innovations to inflation and output growth, in that, both seem to covary positively. More importantly, innovation variance to both inflation and output growth has shown some degree of moderation towards the end of the sample.

Our results point towards a key policy implication. As described in the context of the UC-SV model, there seems to be close association between the trend inflation and inflation expectations. Thus, bringing down inflation following a shock ought to involve monetary policy measures targeting at avoiding the effects of the shock getting embedded into the trend component of the inflation process. In achieving that, a natural way forward would be to maintain a *credible anti-inflation policy,* absence of which, may result in de-anchoring of inflation expectations, and eventually may lead to some spiral effects through changes in the wage- and price-adjustments process (Cecchetti *et al*., 2007 and Mishkin, 2007). A key challenge for any Central Bank would be to avoid de-anchoring of inflation expectations, particularly, at times when there is continued upward pressure on the price level, failing which may result in transforming transitory shocks into more persistent movements in the inflation process.

Finally, this work can be extended along several ways. A more appealing way forward would be to move beyond the TVP-VAR framework to examine the evidence of inflation persistence based on an estimated sticky-price dynamic-stochastic-general-equilibrium (DSGE) model with some form of a hybrid Phillips curve relationship (Benati, 2008). The persistence estimates presented in this study are mainly based on reduced-form evidence, which may surely be necessary; but perhaps be insufficient for conducting dynamic monetary policy, because policymakers may be more interested in understanding the sources of inflation persistence. Such information may greatly help to pin down whether persistence is intrinsic to price- and wage-setting processes; whether it may arise from the behaviour of monetary policy; or it may inherit from rigidities in real activity variables etc. (Fuhrer, 2009). Recently, there has been a lot of work going on in mapping the reduced-form evidence of persistence into underlying structural features of the economy; however, the challenge still remains to a larger extent.

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TABLE 1
SHIFTS IN MEAN INFLATION: STRUCTURAL BREAKPOINT TEST RESULTS

	Qu and Perron (2007) Tests		Andrews and Ploberger (1994) Tests	
	Breakdate	Confidence Interval	Breakdate	p-value
Mean Breaks	1967q3	[1966q4:1968q2]	1967q4	(0.00)
	1978q2	[1976q2:1978q3]	1978q2	(0.00)
	1986q2	[1979q4:1987q2]	1984q2	(0.00)
	1994q2	[1987q4:2001q4]	1994q3	(0.02)
	2002q2	[1988q1:2009q2]	2006q4	(0.09)
Mean Estimates	Sub-period	Estimate	Sub-period	Estimate
	1960q1-1967q2	0.01	1960q1-1967q3	0.01
		(0.00)		(0.00)
	1967q3-1978q1	0.06	1967q4-1978q1	0.06
		(0.01)		(0.01)
	1978q2-1986q1	0.13	1978q2-1984q1	0.15
		(0.01)		(0.01)
	1986q2-1994q1	0.11	1984q2-1994q2	0.10
		(0.01)		(0.01)
	1994q2-2002q1	0.09	1994q3-2006q3	0.08
		(0.01)		(0.01)
	2002q2-2009q4	0.10	2006q4-2009q4	0.12
		(0.01)		(0.02)

Notes:
Results are based on quarterly CPI inflation defined at an annual rate, over the sample 1960q1-2009q4. Inflation series is regressed on a constant. For QP (2007) tests, 90 percent confidence intervals are reported in brackets. For AP (1994) tests Hansen (1997) *p*-values for the *exponential Wald F*-statistic are reported in parentheses (results are robust across alternative test-statistics, namely, *maximum* and *mean Wald F*-statistics). We use a trimming parameter used is 15%; and a heteroskedasticity-consistent covariance matrix. In the lower panel, estimates of mean inflation are reported with White-heteroskedasticity-consistent standard errors.

TABLE 2
OLS ESTIMATES OF INFLATION PERSISTENCE ACROSS BREAKDATES

	Breakdate	Confidence Interval
Persistence Breaks	1971q1	[1970q4:1973q4]
	1981q1	[1979q1:1983q1]
	1991q4	[1990q3:1992q3]
Persistence Estimates	Sub-period	Estimate
	1960q1-1970q4	0.42
		(0.17)
	1971q1-1980q4	0.77
		(0.17)
	1981q1-1991q3	0.89
		(0.08)
	1991q4-2009q4	0.61
		(0.11)

Notes:
Results are based on Qu and Perron (2007) tests, with quarterly CPI inflation defined at an annual rate, over the sample 1960q1-2009q4. . Persistence breaks are estimated after allowing for breaks in the mean inflation, and based on AR (5) specification (without an intercept) as suggested by AIC information criterion. The 90 percent confidence intervals are reported in brackets. We use a trimming parameter used is 20 %, and a heteroskedasticity-consistent covariance matrix. In the lower panel, persistence estimates are reported with White-heteroskedasticity-consistent standard errors.

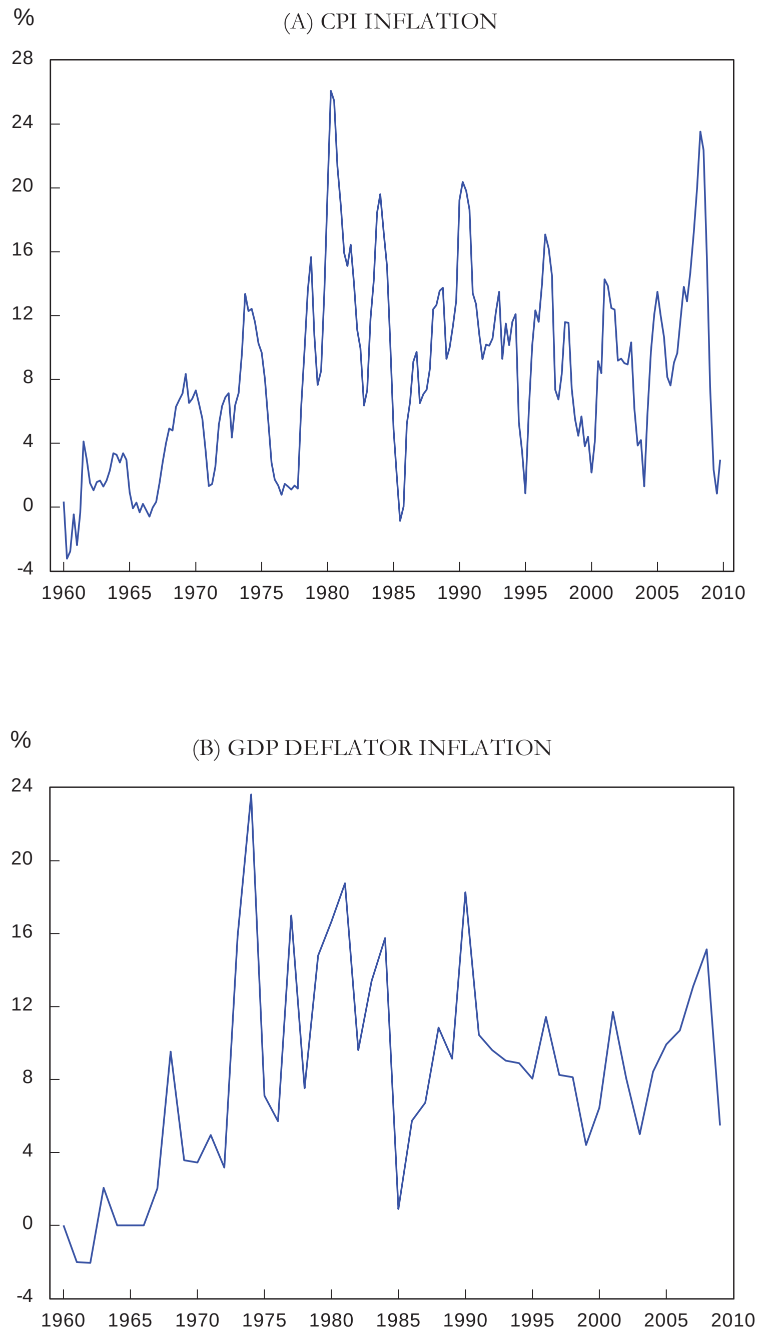


FIGURE 1: INFLATION MEASURES 1960-2009
(A) CPI inflation is quarterly at an annual rate, and
(B) GDP Deflator Inflation is annual

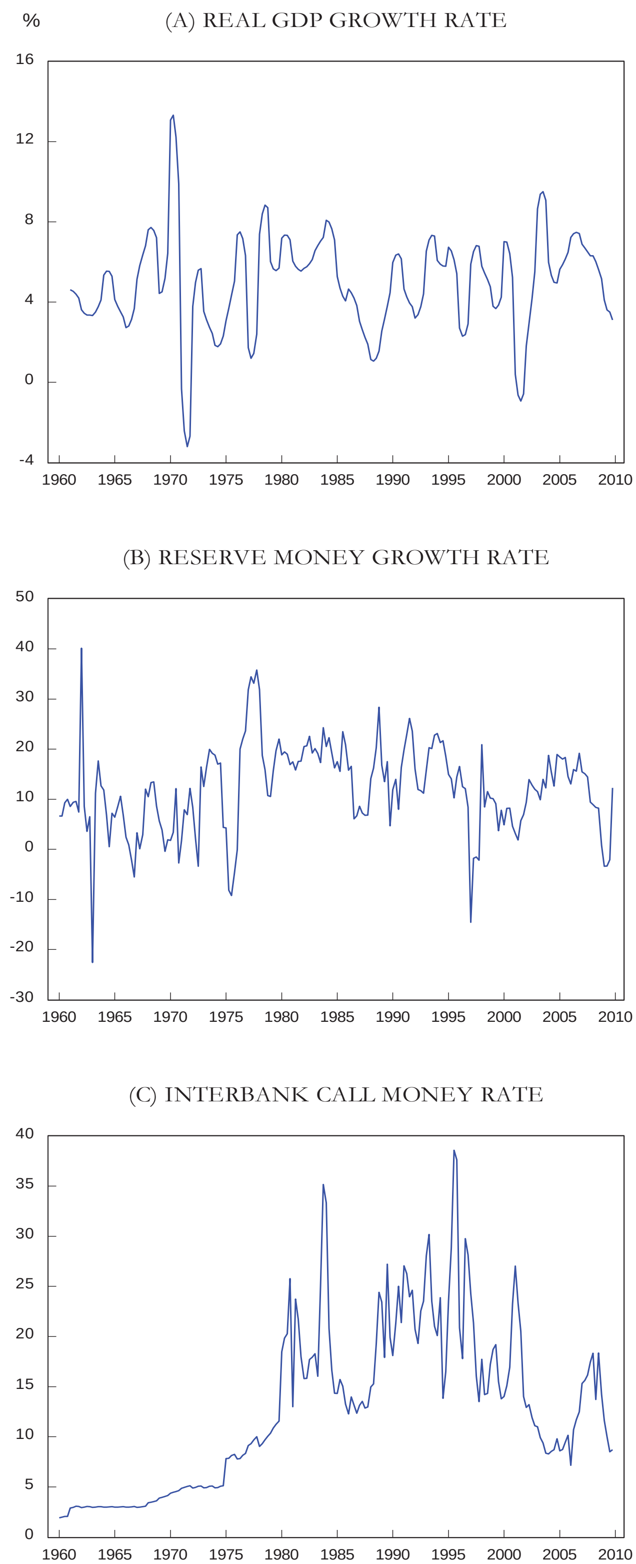


FIGURE 2: REAL GDP GROWTH, RESERVE MONEY GROWTH AND INTEREST RATES: 1960-2009

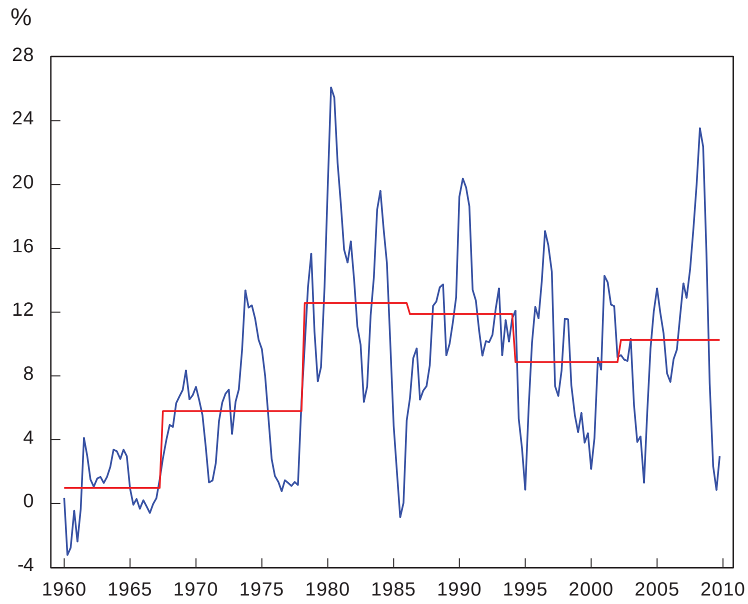


FIGURE 3: ESTIMATED BREAKS IN THE MEAN OF CPI INFLATION

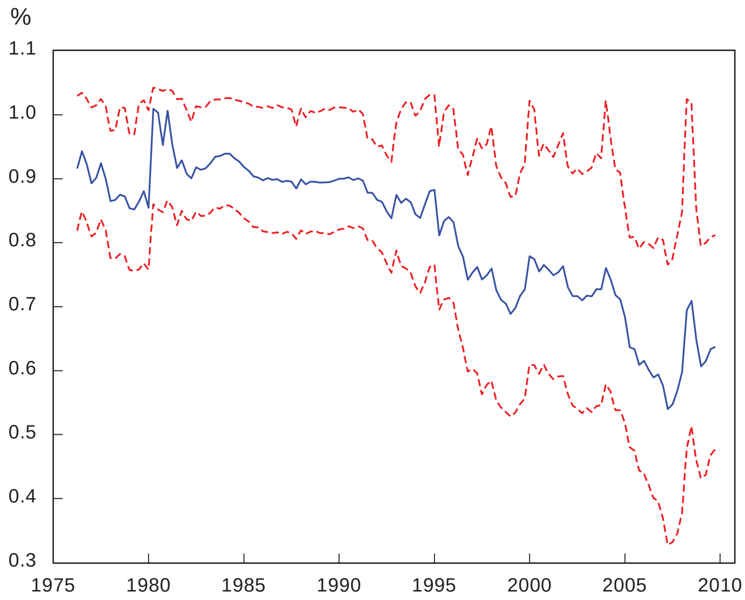
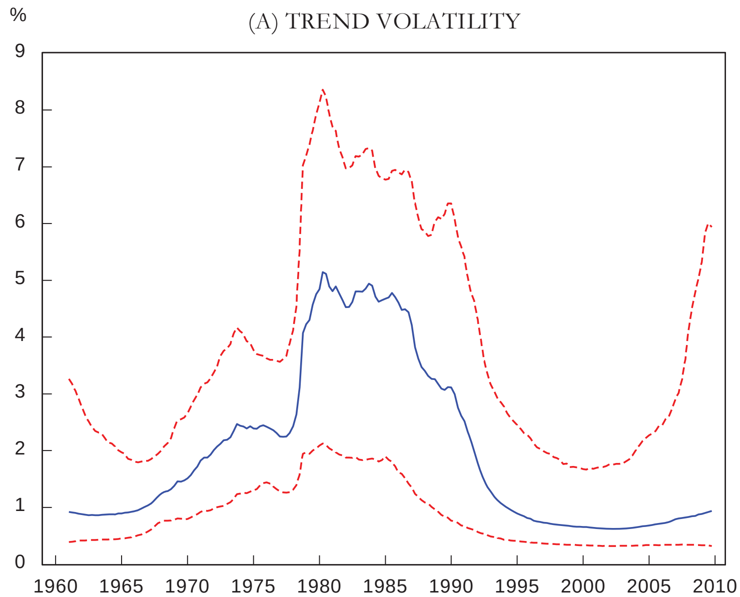


FIGURE 4: MUE ESTIMATES OF INFLATION PERSISTENCE: CPI INFLATION

Median-unbiased and 90 percent confidence interval estimates of the sum of AR(6) coefficients over 15-year rolling window samples, obtained with Hansen (1999) grid-bootstrap procedure



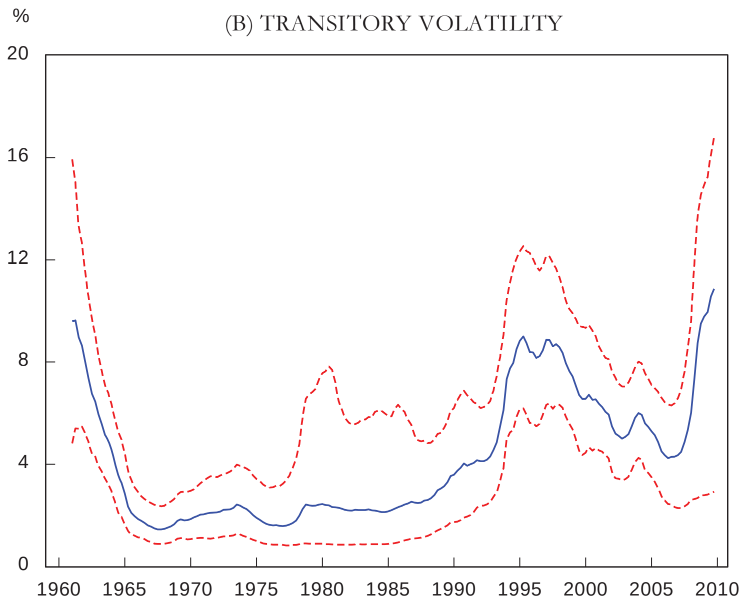


FIGURE 5: ESTIMATES OF STANDARD DEVIATIONS OF SHOCKS TO THE TREND AND TRANSITORY COMPONENTS

Based on the UC-SV (0.2,0.8) Model: 16.5%, 50% and 83.5% Quantiles of the Posterior Distribution, CPI inflation 1960q1-2009q4

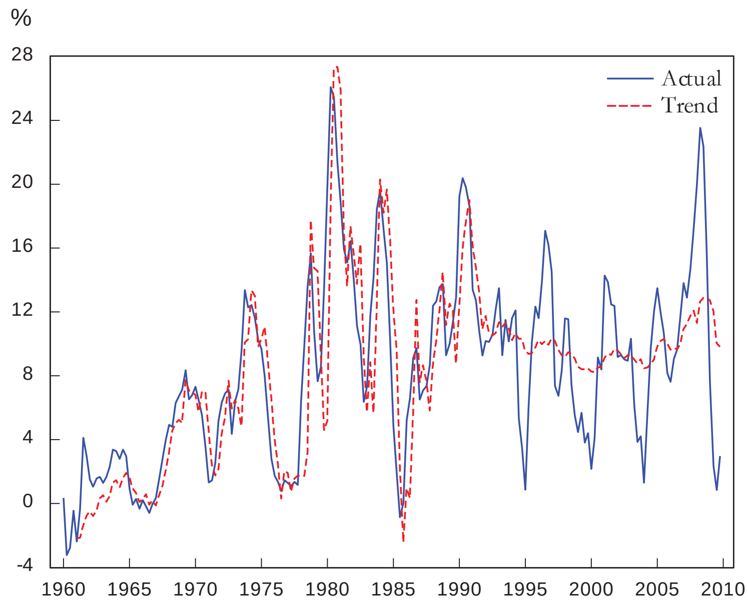


FIGURE 6: ACTUAL AND TREND INFLATION: CPI INFLATION

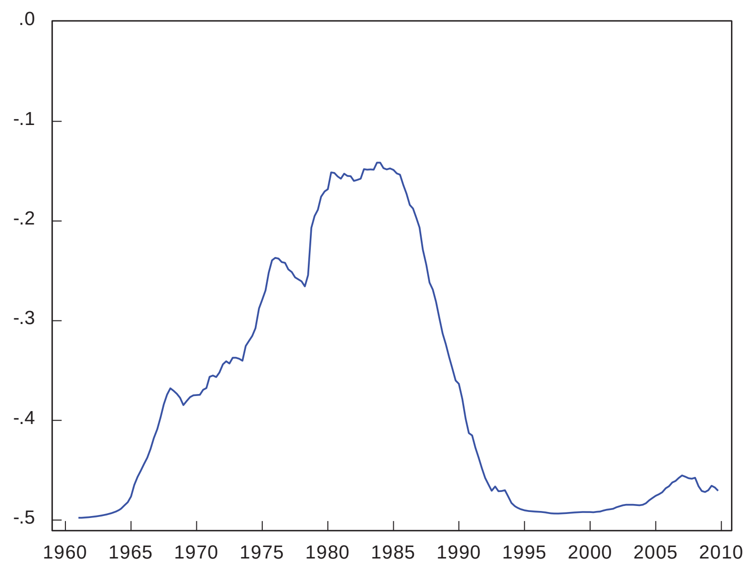


FIGURE 7: ESTIMATES OF INFLATION PERSISTENCE: THE UC-SV (0.2,0.8) MODEL-CPI INFLATION

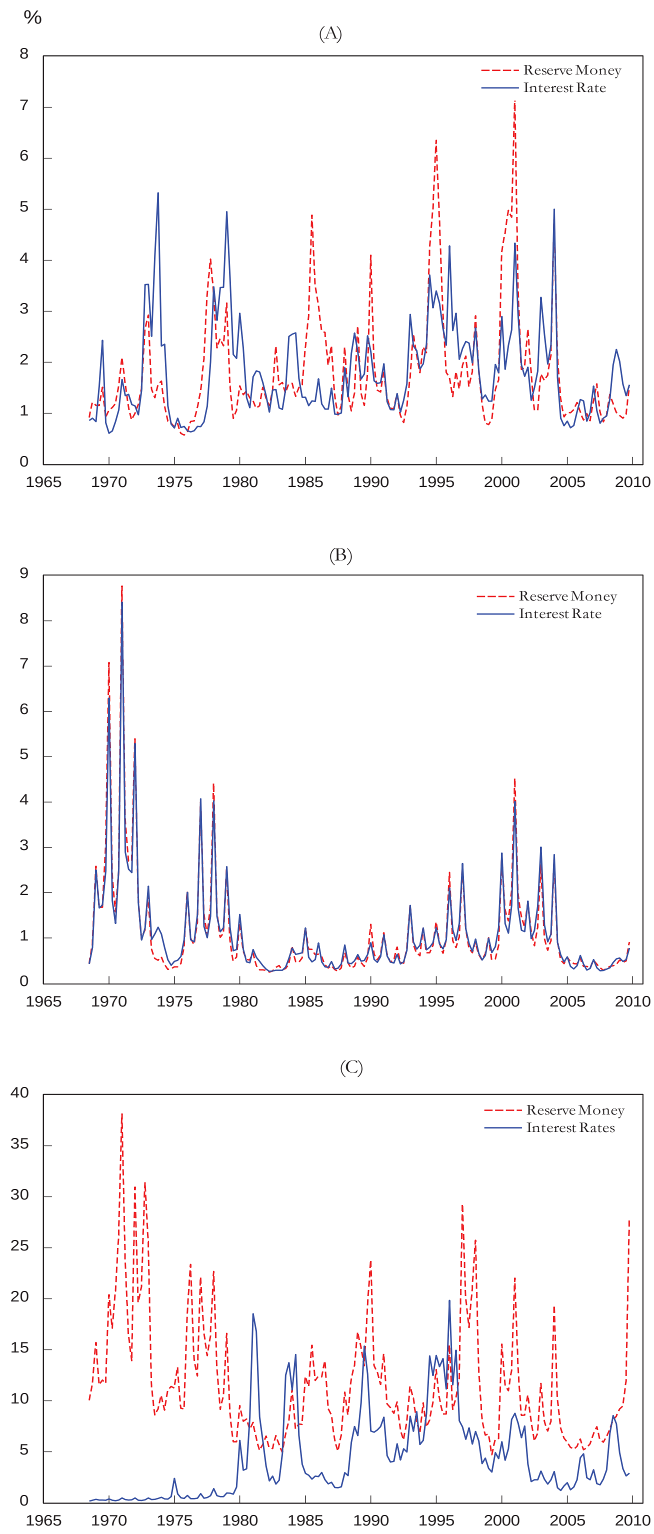


FIGURE 8: STANDARD DEVIATIONS OF INNOVATIONS TO (A) INFLATION EQUATION, (B) GDP GROWTH EQUATION, AND (C) POLICY VARIABLE EQUATION