Advances in Economics, Business and Management Research (AEBMR), volume 60
4th Annual International Conference on Management, Economics and Social Development (ICMESD 2018)

Insight into Inflation: Persistence, Variability and Predictability

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Keywords: Inflation, Persistence, Variability, Predictability.

Abstract. This paper provides a macroeconomic analysis of US inflation and its persistence from 1947 to 2007 and three subperiods. An ARFIMA-GARCH model is estimated to capture the stylized facts of inflation dynamics and investigate the causalities between persistence and the level of aggregate inflation, and persistence and inflation uncertainty, as well as predictability of inflation and its volatility. The main findings point to a rather low inflation persistence, a time-varying persistence positively correlated with inflation reflecting monetary policy switches and a moderate predictability of inflation and its volatility.

Introduction

The phenomenon of inflation has been observed over time. However, it is only in the postwar period that inflation did become persistent rather than occasional and temporary. Persistence arises and the inflation process tends to approach its mean level slowly rather than instantly, which contains implications for monetary policy. Inflation persistence and its social, political and economic consequences are at the center of debates in the literature studying U.S. inflation to gain a better understanding in the dynamics of inflation.

Studies on inflation persistence have focused on two issues: i) the dynamics of inflation exhibit substantially high or low persistence, and ii) inflation persistence is time variant or invariant. It has been widely agreed that inflation persistence was very high from 1965 to the early 1980s. Whereas low inflation persistence during the Volcker-Greenspan era is reported by among others, Cogley and Sargent [4] and Williams [9]. Also evidence of low inflation persistence in the 1947-1959 period and the 1960s has also been found by Barsky [2] and Evans and Wachtel [5], respectively. These authors favour the view that inflation tends to return to its mean after a quick adjusting shift following a shock, meaning that therefore inflation is less persistent. On the other hand, Fuhrer and Moore [6] documente extremely high inflation persistence during the postwar period, approaching that of a random walk process. This implies that the best forecast of next year’s inflation is the most recently observed inflation rate, and it is unlikely to converge to its mean after a shock. Pivetta and Reis [8] find that US inflation is best described as high and time invariant since 1965.

Another feature of postwar inflation process is the endurance of a number of structural breaks, which occur due to exogenous shocks . When such breaks fail to be considered, a spurious estimate of persistence could be produced, leading to the conclusion that time series behaves under a persistent pattern even if it does not. Levin and Piger [7] illustrate this point by showing the existence of high inflation persistence for twelve industrial countries when structural breaks are not taken into account and much lower persistence when allowing for structural breaks. These changes may also result in stochastic variance in the inflation process which can be captured using a Generalised Autoregressive Conditional Heteroskedasticity (GARCH) model by Bollerslev [3].

If inflation does not follow a random walk, can it be predicted? Atkeson and Ohanian [1] test the predictive quality of non-accelerating inflation rate of unemployment (NAIRU) Philips curve (PC) to predict the consumer price index (CPI), core CPI and personal consumption expenditure (PCE) deflator for the period 1985 to 2000, claiming a poor forecast performance. In 2002, Fisher et al, examining three sample periods, extend this work, and report that the PC models forecast core CPI well in 1977-1984 but poorly during both 1985-1992 and 1993-2000. Moreover, the work of Cogley and Sargent [4] shows that "during the 1970s” and "Between 1979 and 2000…inflation became even easier to forecast one-quarter ahead" (pp. 23-33).

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This paper employs a univariate GARCH model to inflation spanning postwar period and subsamples with switching monetary regimes, capturing the degree of inflation persistence, considering the intrinsic source of the persistence, and investigating the causality between persistence and aggregate inflation, and persistence and inflation uncertainty. Four alternative loss functions are applied to measure the forecast performance of the estimated models, and hence examine the predictability of inflation and inflation volatility.

The Model

The reaction of a series to shocks can be catalogued into three types: the persistence decays at an exponential rate (short memory) or hyperbolic rate (long memory) or infinitely (perfect memory), which delivers the interpretation of the degree of a time series dynamics integrating at zero, fraction or unity respectively. To capture the significant autocorrelation between observations of a time series dynamic, that is, autoregressive fractionally integrated moving average (ARFIMA) model with the flexibility of allowing fractional orders of integration. To model heteroskedasticity, Bollerslev [3] reduced the number of parameters of Auto Regressive Conditional Heteroskedasticity (ARCH) from infinity to two and proposed the GARCH model.

The general model in this paper of ARFIMA (*n*, *d*, *m*)-GARCH (*p*, *q*) is written as:

$$\phi(L)(1-L)^d(\pi_t-\mu-\delta Vol_t)=\theta(L)\varepsilon_t \tag{1}$$

$$\beta(L)\sigma_t^2=\omega+\alpha(L)\varepsilon_{t-i}^2 \tag{2}$$

where π_t is inflation, the inflation persistence driving factor d is between zero and unity, μ is intercept, L is the lag operator. $\phi(L)=1-\sum_{i=1}^{n}\phi_i L^i$, $\theta(L)=1+\sum_{i=1}^{m}\theta_i L^i$, $\beta(L)=1-\sum_{i=1}^{p}\beta_i L^i$, $\alpha(L)=1-\sum_{i=1}^{q}\alpha_i L^i$, and all the root of $\phi(L)$, $\theta(L)$, $\beta(L)$ and $\alpha(L)$ lie outside the unit circle. ω, α and β are positive and $\alpha(L)+\beta(L)<1$, which satisfy the positivity constraint. Vol_t , the repressor in the conditional mean, denotes the realized inflation volatility and allows lags of volatility to affect inflation. The innovations ε_t are under the assumption of a student-*t* distribution with *v* degrees of freedom, mean zero and the standard deviation σ_t conditional on information set up to time *t*-1, following a GARCH process.

Data Description and Estimation Results

To measure inflation I use monthly aggregate not seasonally adjusted CPI for all urban consumers in the postwar period (1945:09-2007:04) taken from the U.S. Bureau of Labor Statistics, which is right before the global financial crisis of 2008. Inflation in this paper is defined as the natural log difference of CPI, that is, $\pi_t=100*(\log CPI_t-\log CPI_{t-1})$.

Figure 1 shows the inflation rates and realized inflation volatility in the US, fluctuating as prices tend to rise. Up to 1950, the inflation was extremely high and volatile peaking at nearly 6% in July 1946, then dropped down to 0.99% in September 1946 and remained at -0.4% or so from October 1948 to January 1950, since the whole society was still recovering from the war with fear of the subsequent drop in military spending and the pent-up consumer demand surpassing market supply. Low inflation occurred from 1950 to the end of 1960. This period is described as postwar prosperity. By contrast, in the late 1960s to the early 1980s inflation rose. Throughout the 1970s and the early 1980s, the monthly inflation rate was around 1%, peaking during the months of 1974, 1975 and 1979. Apparently, this Great Inflation was the result of several events, such as the oil price shocks of 1973-1974 and 1979. Then US experienced a dramatic drop in inflation with a 3% annual rate in 1983 and disinflation in the end of 1982 and first quarter of 1986. During the past two decades, inflation has been less volatile and has not exceeded at an annual rate 3%.

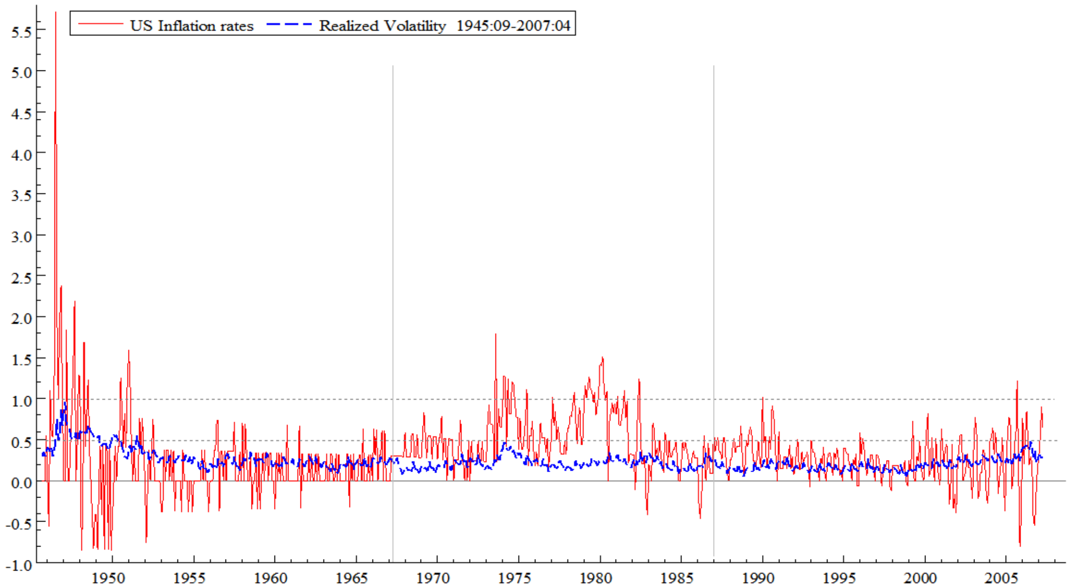

Fig 1. US inflation rates and realized inflation volatility

Given the dynamics of inflation described above, I divide the series into three subsamples to better examine inflation persistence. Table 1 presents the data descriptive statistics including ARCH_LM, normality and Chow tests. The tests reject normality, confirm the two structural breaks, and show the existence of ARCH effects in the series in the residuals, that is, heteroskedasticity.

Table 1. US inflation descriptive statistics

	Sample			
	1945:09-1967:02	1967:03-1986:12	1987:01-2007:04	1945:09-2007:04
Obs.	258	238	244	740
Mean	2.31613	5.09052	2.56641	3.29096
Variance	34.6739	12.4898	7.29241	20.0565
ARCH_LM	8.9721 [0.0002]	7.6974 [0.0006]	10.799 [0.0000]	55.208 [0.0000]
Normality	23.337 [0.0000]	36.324 [0.0000]	14.588 [0.0007]	108.36 [0.0000]
Chow test		3.3255 [0.0049]	6.6859 [0.0001]	8.5637* [0.0000]

Notes: Obs.denotes the number of observations. The numbers in brackets are *p*-values. *This is the Chow test of joint break points of 1967:02 and 1986:12.

To identify such a stylized fact of the persistence of inflation dynamics, several unit root tests are employed. A standard Dickey-Fuller test is used for the null hypothesis of a unit root against the alternative of staionarity. In the case of the serial correlation at high orders, the Augmented Dickey-Fuller (ADF) test is widely used, which is described as . In contrast to the ADF test, the null hypothesis in the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test is that the series is stationarity, that is I (0). The KPSS is based on the statistic , where and is an estimator of the residual spectrum at frequency zero. Table 2 reports that the ADF test statistic is -5.0685 at 1% significance level, which indicates that US inflation does not follow I (1), and the statistic for KPSS test is 0.505, which implies that the test failed to reject the inflation following I(0) at 1% significance level but rejected the null at 5% significance level. Thus both the ADF and KPSS tests reject the null at the 5%

significance level, indicating that the inflation process is best described as I (*d*), rather than I (1) or I (0).

The equations (1)-(2) for the US inflation series are estimated by maximizing the log-likelihood function and the preferred specification is selected using the Akaike information criterion (AIC). Table 3 reports the MLE estimates of the selected ARFIMA(n, d, 0)-GARCH(1,1) ~ student-t model, allowing lagged volatility as exogenous variable affecting the inflation rate. The estimated values of *d* for all subsamples and full sample are between zero and 0.5, which implies that the inflation process is covariance stationary. The estimated values of d are 0.268, 0.270 and 0.287 for the 1945:09-1967:02, 1987:01-2007:04 and 1945:09-2007:04 samples respectively. They are relatively low but significantly different from zero. While the estimated value of d for the 1967:03-1986:12 sample is 0.433, which is higher. This evidences that US inflation does possess a long memory feature.

Table 2. Unit root tests for full sample

	ADF H_0: I(1)	c_0	t_{c0}	c_1	t_{c1}	$t_{\lambda k}$	KPSS H_0: I(0)	η_μ
π_t		0.656	0.189	-0.223	-5.069*	9.586		0.505**

Notes: 1% significance level of ADF and KPSS are -3.439 and 0.739 respectively and number of lag (k) in ADF test reported is one. The optimal lag length of ADF test is 10 according to the AIC criterion. KPSS test is based on Bartlett Kernel using 8 lags.
*Significant at 1% level; **Significant at 5% level.

Table 3. ARFIMA (*n*, *d*, *0*)-GARCH (1, 1)~student-*t* estimation results
(Realized volatility as exogenous variables)

	Sample			
	1945:09-1967:02	1967:03-1986:12	1987:01-2007:04	1945:09-2007:04
d	0.26794 (0.07835)	0.43376 (0.07451)	0.26956 (0.08923)	0.28705 (0.06529)
Vol_t	-0.21697 (0.44742)	0.55177 (0.43314)	0.43688 (0.36472)	0.59732 (0.30693)
ϕ_m	-0.25524 (0.08929)	0.1561 (0.06607)	0.32522 (0.06275)	0.18542 (0.03784)
α_1	0.12731 (0.04941)	0.29566 (0.29566)	0.14766 (0.05246)	0.16064 (0.04654)
β_1	0.84729 (0.05085)	–	0.8453 (0.04332)	0.80631 (0.05295)
V	6.34288 (2.637)	6.15124 (2.5032)	11.87 (8.1987)	8.34065 (2.2818)
Q(12)	18.2413 [0.109]	10.6924 [0.555]	18.6865 [0.096]	18.5114 [0.101]
$Q^2(12)$	24.9632 [0.015]	6.3203 [0.899]	7.5029 [0.823]	13.3526 [0.344]
Ex. kurtosis	5.560951	5.789089	3.762389	4.382281
AIC	-97.6238	-17.0872	21.4043	-106.301
Log' (*L*)	-89.6238	-10.0872	32.4043	-97.301
LR	0.4112	2.5974	1.5308	7.804*

Notes: Standard errors and t- probabilities are given respectively in parentheses and brackets. Ex. kurtosis is excess kurtosis and calculated by $(3v-6)/(v-4)$ for $v>4$. Q (12) and Q^2 (12) are the Box Pierce tests based on residuals and squared residuals. ϕ_m only reports the last lag of AR term., Log' (*L*) is log likelihood, and LR is the likelihood ratio test ~ $\chi^2(1)$. Sample 1945:09-1967:02 reports Vol_{-1} and 1945:09-2007:04 reports Vol_{-6}.
*Significance at 1% level.

The above results suggest that there is a clear clue that inflation dynamics are more or less persistent as inflation rates increase or decrease, which is essentially associated with switches of monetary policy to readjust them. In the 1950s and early 1960s, the Federal Reserve (the Fed) used price and wage controls to prevent the price increases when Korean War started. As a result the Fed achieved a remarkable record of price stability in the inflation rate averaged 0.3 from March 1952 to February 1967 and the estimated degree of persistence is 0.27. Starting from the end of 1960s, the inflation rates rose throughout the 1970s up to a level averaged around 0.55 and peaking at 1% per month, which nearly doubled the rates of previous decade.

The Fed's dual goal of maximum sustainable employment and price stability, which were prescribed by the 1977 amendment to the Federal Reserve Act, were challenged by this economic situation: high inflation induced high wage demands and expected inflation, which fed back into high inflation and high unemployment. In the Great Inflation period, the estimated degree of persistence is 0.43, which is significantly higher. Observing high inflation and persistence due to other exogenous events such as the Vietnam War (1966-1974), the collapse of Bretton Woods Agreement on fixed exchange rates (1971) and the oil price shocks (1973-1974, 1979), the Fed under Paul Volcker switched to setting strict money supply growth targets in contrast to past policies of controlling interest rates (Conte and Karr, 2001). By ending stagflation in early 1980s, US ushered in the low inflation since then. The succeeding chairman Alan Greenspan led the Fed to keep vigilant about controlling price increases and reacting quickly, for instance, by raising interest rates, to lower inflation (Conte and Karr, 2001). Undoubtedly, the inflation persistence decreases to its level of 1950s-1960s with an estimated degree of 0.27.

Forecasting Inflation and Inflation Volatility

Forecasting inflation and volatility has been considered a useful guide to adjusting monetary policy. However, evaluating the quality of different forecasting models is very difficult, since there does not exist a unique criterion capable of selecting the best model(See Bollerslev, Engel and Nelson (1994), and Lopez (2001)). At present, there is a widespread tendency to focus on some particular statistics such as the Mean Squared Error. Thus, to assess the performance of the fitted ARFIMA-GARCH model, the following measures (loss functions) are computed to examine the model's predictive capability.

Mean Squared Error (MSE)

$$\mathrm{MSE} = T^{-1}\sum_{t=1}^{T}(x_{t+h} - \hat{x}_{t+h|t})^2 \tag{3}$$

where $x = \pi, \sigma$ and $\hat{x} = \hat{\pi}, \hat{\sigma}$, T is the sample size and h is the number of steps ahead. In particular, π_{t+h}, $\hat{\pi}_{t+h|t}$, $\sigma^2{}_{t+h}$ and $\hat{\sigma}^2_{t+h|t}$ denote actual inflation, forecasted inflation, realized volatility and forecasted volatility, respectively, in period $t+h$.

Root Mean Squared Error (RMSE)

$$\mathrm{RMSE} = \sqrt{T^{-1}\sum_{t=1}^{T}(x_{t+h} - \hat{x}_{t+h|t})^2} \tag{4}$$

Mean Absolute Error (MAE)

$$\mathrm{MAE} = T^{-1}\sum_{t=1}^{T}\left|x_{t+h} - \hat{x}_{t+h|t}\right| \tag{5}$$

Mincer - Zarnowitz R^2 (R^2)

The Miner-Zarnowitz regression has been largely applied to evaluate forecasts. For the conditional variance, it is computed by regressing the forecasted variables on the actual variables: $x = c + b\hat{x}_{t+h|t} + u_{t+h}$. The $\boldsymbol{R}^2$ statistic of this regression provides, therefore, the proportion of the variance of the actual variables explained by the forecast, that is, the higher the $\boldsymbol{R}^2$ the better the forecast.

Table 4 and 5 report the above four different forecasting error measures of inflation and inflation volatility for each subsample and the full sample. Note $\hat{\pi}$ and $\hat{\sigma}$ are one-step-ahead ex-post forecasts for the estimated models above. The maximum $\boldsymbol{R^2}$ is approximate 0.17 for the inflation in the 1987:01-2007:04 subsample, and 0.31 for inflation volatility in the 1967:03-1986:12 and the full sample.

Table 4. Out-of-sample predicting inflation performance of
ARFIMA (*n*, *d*, *0*)-GARCH (1, 1)~ student-*t*

	Sample			
	1945:09-1967:02	1967:03-1986:12	1987:01-2007:04	1945:09-2007:04*
MSE	0.050	0.0600	0.1400	0.1458
RMSE	0.2229	0.2450	0.3742	0.3818
MAE	0.1886	0.1845	0.2935	0.3013
R^2	0.0217	0.1090	0.1689	0.1305

Notes: * Realized volatility as exogenous variables.

Table 5. Out-of-sample predicting inflation volatility performance of
ARFIMA (*n*, *d*, *0*)-GARCH (1, 1)~ student-*t*

	Sample			
	1945:09-1967:02	1967:03-1986:12	1987:01-2007:04	1945:09-2007:04*
MSE	0.0043	0.0061	0.0071	0.0103
RMSE	0.0658	0.0778	0.0845	0.1017
MAE	0.0513	0.0601	0.0681	0.0801
R^2	0.1405	0.3098	0.2588	0.3098

Notes: As in table 4.

Conclusion

This paper investigates US aggregate inflation in the post war period. A powerful ARFIMA-GARCH model was estimated with MLE, capturing the stylized facts of inflation persistence, stochastic variance and structural breaks for the full sample and three subsamples. Results clearly rejected the hypothesis of that inflation possesses substantially high persistence, approaching a random walk.

Another core finding is that inflation persistence is positively associated with the inflation rates, reflecting the switches in monetary policy. Meanwhile, there is no clear demonstration that inflation volatility has an effect on inflation persistence. Interestingly, only the results obtained from the full sample show that inflation volatility causes inflation, and the predictability of inflation and volatility were not strong. Also the macroeconomic analyses indicate a time-varying and relatively low persistence, a positive relation between inflation and its persistence, and suggest that future research should attempt to improve the predictability of inflation and its volatility.

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