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Inflation, inflation uncertainty and output growth in the USA

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ABSTRACT

Employing a multivariate EGARCH-M model, this study investigates the effects of inflation uncertainty and growth uncertainty on inflation and output growth in the United States. Our results show that inflation uncertainty has a positive and significant effect on the level of inflation and a negative and significant effect on the output growth. However, output uncertainty has no significant effect on output growth or inflation. The oil price also has a positive and significant effect on inflation. These findings are robust and have been corroborated by use of an impulse response function. These results have important implications for inflation-targeting monetary policy, and the aim of stabilization policy in general.

1. Introduction

The relationship between inflation uncertainty, inflation, output growth uncertainty and output growth is always interesting and controversial for economists. Recently, most of the central banks are fraught by trying to keep inflation low. Inflation is increasing all over the world due to rising oil and commodity prices. It seems that monetary policy in most the countries, and especially in the US, is not effective in maintaining low inflation and stable economic growth. Declining economic growth most probably will be the cause of recession.

Economists are divided regarding the relationship between inflation and growth. There are several studies in which economists have found positive, negative or no relationships between inflation and growth. Thus it is not surprising that the empirical literature on this subject is divided. But most economists agree that the cost of higher inflation and inflation uncertainty on growth and welfare are significant, especially in the context of a rising oil price environment. Much attention has been focused on the relationship between inflation and inflation uncertainty. Although there are a few studies in the areas of inflation uncertainty, growth uncertainty and growth, we believe that the coverage of the topic is not adequate, and as such more investigations are required in this area.

While both theoretical and empirical literature on inflation–growth relationships remains unresolved, there is another, less studied, link between the inflation process and economic performance.[1] Both Okun [2] and Friedman in his 1977 Nobel Lecture [3] argue that increased uncertainty reduces the information function of price movements and hinders long-term contracting, thus potentially reducing growth. Friedman [3] also argues that high inflation leads to higher inflation uncertainty. Ball [4] formalizes the positive relationship between inflation and inflation uncertainty. In Ball's model, the public does not know the preferences of the policy maker, but uncertainty of the policy maker's preferences only affects inflation uncertainty when inflation is high.

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1 For a good survey of both theoretical and empirical literature, see [1].

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Thus, more recent studies use conditional variance as a measure of uncertainty, following the path-breaking work of Engle [5] on the autoregressive conditional heteroskedasticity (ARCH) approach. The studies (e.g. [1,6,7]) that use the generalized ARCH (GARCH) approach, find significant positive relationships between inflation and inflation uncertainty and significant negative impacts of inflation and inflation uncertainty on growth in industrialized countries.[2] Using ARIMA–GARCH, Payne [12,13] found that inflation increased the inflation uncertainty for the US and Thailand. Using bivariate GARCH modelling, both Shields et al. [14] and Grier et al. [7] found that inflation uncertainty decreased inflation and output growth for the US, but output uncertainty increased growth but reduced inflation. There are only a few such studies (e.g. [15,16]) involving middle-income countries. Nas and Perry [15] found that inflation significantly raised inflation uncertainty in Turkey during the period 1960–1998. Their study does not include the effect of inflation uncertainty on growth. Using multivariate EGARCH-M, Grier and Grier [16] found that inflation uncertainty had a negative and significant effect on output growth in Mexico during the period 1972–2001. Berument and Dincer [17] found that inflation caused inflation uncertainty for G-7 countries using a "Full Information Maximum Likelihood Method" with extended lags.

The examination of the impact of inflation on inflation uncertainty is crucial according to Okun [2] and Friedman [3], as it is through inflation uncertainty that high inflation can adversely affect economic growth. That is, if high inflation does not cause inflation uncertainty then we are unlikely to observe a negative relationship between inflation and economic growth.

Most of the studies have used a univariate GARCH or EGARCH specification for the estimation of the inflation uncertainty. Univariate models do not allow studying the joint determination of more than one series. This problem can be overcome by using a bivariate model. Grier et al. [7] and Shields et al. [14] used a bivariate GARCH specification for the estimation of the inflation uncertainty and output uncertainty. However, there are some disadvantages of the use of GARCH modelling. Our paper differs from the previous papers in two ways. First, in this paper we have used bivariate EGARCH modelling, which we believe to be a better approach. This approach also allows us to discuss time-varying correlation between inflation and output growth. Bivariate EGARCH developed by Nelson [18], captures potential asymmetric behaviour of inflation and output growth and avoids imposing non-negativity constrains in GARCH modelling by specifying the natural logarithm of the variance ($\ln \sigma_t^2$). It is no longer necessary to restrict parameters in order to avoid negative inflation and output uncertainty. Secondly, we have included a newly constructed oil price dummy to capture the impact of oil price[3] on inflation. Thus, this paper aims to re-examine the inflation–growth relationship in the US by employing a more appropriate econometric method, the multivariate EGARCH-M model. The use of higher frequency data makes it possible to use EGARCH-M model to estimate inflation uncertainty and investigate the impact of inflation on inflation uncertainty, and hence on growth.

Thus the hypotheses we are going to test are as follows.

(i) Does inflation uncertainty reduce economic growth?
(ii) Is there a significant relationship between inflation and inflation uncertainty?
(iii) Does the oil price have any influence on the level of inflation?

The paper is organized as follows: Section 2 provides a brief review EGARCH methodology and data description. Section 3 explains the estimated results and checks the robustness of findings by using appropriate diagnostic tests and explains the statistical significance of innovations of the variables using Generalized Impulse Response Function. Section 4 contains concluding remarks.

2. Model specification and data description

A brief description is provided here for the bivariate EGARCH model with time-varying correlations relating the growth rate in output and the inflation. We denote the inflation by π_t, the annualized monthly difference of the natural logarithm of P_t, the producer price index: $[(\ln P_t - \ln P_{t-1}) \times 1200]$ and the growth rate in output by Δy_t, the annualized monthly difference of the natural logarithm of y_t, the industrial production index: $[(\ln y_t - \ln y_{t-1}) \times 1200]$ for the period April 1957 to April 2007. The data used in this study are obtained from the DX-Econ data-OECD Main Economic Indicators.[4] The interaction of the expectation part with the risk (captured by contemporaneous standard deviation of the residual) in the relationship is described by the following equations:

$$\pi_t = \alpha_\pi + \beta_{\pi,1}\pi_{t-1} + \beta_{\pi,2}\pi_{t-2} + \beta_{\pi,3}\Delta y_{t-1} + \beta_{\pi,4}\Delta y_{t-2} + \beta_{\pi,5}\sigma_{\pi,t} + \beta_{\pi,6}\sigma_{\Delta y,t} + \beta_{\pi,7}D_{\text{oil},t} + \varepsilon_{\pi,t}, \tag{1}$$

$$\Delta y_t = \alpha_{\Delta y} + \beta_{\Delta y,1}\pi_{t-1} + \beta_{\Delta y,2}\pi_{t-2} + \beta_{\Delta y,3}\Delta y_{t-1} + \beta_{\Delta y,4}\Delta y_{t-2} + \beta_{\Delta y,5}\sigma_{\pi,t} + \beta_{\Delta y,6}\sigma_{\Delta y,t} + \varepsilon_{\Delta y,t}, \tag{2}$$

where $\sigma_{\pi,t}$ and $\sigma_{\Delta y,t}$, the standard deviations of the residuals of the inflation and the growth rate in output, are our inflation uncertainty and growth uncertainty, respectively. In Eq. (1), Δy_{t-1} and Δy_{t-2} will capture the lagged output effect on

[2] Also, see [8] for uncertainty on macroeconomic performance; [9] for inflation and inflation uncertainty in the UK; [10] for inflation and inflation uncertainty for developed and emerging countries; and [11] for inflation-uncertainty hypotheses in the US, Japan and the UK.

[3] Previous studies failed to incorporate the oil price while calculating the inflation uncertainty. An increase in oil price can increase inflation directly by raising the energy cost component of inflation and indirectly by increasing the cost of production. Therefore, the inclusion of an oil price dummy in this research is most appropriate.

[4] Data used in this study are seasonally adjusted. We have also checked the data and no seasonal variations were found. Notably, previous researchers, e.g. Shields et al. [14] and Grier [7], did not use a seasonal dummy.

inflation and $\sigma_{\pi,t}$, $\sigma_{\pi,t}$ and $D_{\mathrm{oil},t}$ will capture the effect of inflation uncertainty, growth uncertainty and oil price effect on inflation, respectively. Similarly, in Eq. (2), π_{t-1} and π_{t-2} will capture the lagged inflation effect on output growth and $\sigma_{\pi,t}$, $\sigma_{\pi,t}$ and $D_{\mathrm{oil},t}$ will capture the effect of inflation uncertainty, growth uncertainty and oil price effect on output growth, respectively. Because our main aim in this paper to investigate the relationship between inflation, output growth, inflation uncertainty and growth uncertainty, we believe this multivariate EGARCH in mean model will be most appropriate. Shields et al. [14] and Grier et al. [7] used a similar model previously. As we know from the experience of the 1970s, oil price increases could be an important cause of inflation and output slowdowns. Thus, we have introduced a dummy variable for the oil price (D_{oil}) in the inflation equation.

The oil price dummy is constructed by first converting the oil price into local currency. This is because an appreciating exchange rate can offset the impact of oil price increases. When the oil price (in local currency) increases more than 4% in three periods consecutively, we consider the dummy equal to +1. Similarly, we have used the dummy as −1 if the oil price decreases more than 4% in three periods consecutively. The dummy is zero otherwise. This method of constructing the oil price dummy is an improvement over that in [19].[5]

These are more fully defined as part of the covariance matrix below:

$$\begin{bmatrix} \varepsilon_{\pi,t} \\ \varepsilon_{\Delta y,t} \end{bmatrix} \Bigg| \Omega_t \sim N(0, \Sigma_t). \tag{3}$$

As indicated above by Eqs. (1) and (2), we assume a bidirectional influence in the mean parts for both inflation and output growth rate. The extent and nature of these influences will be determined by the data and discussed in the empirical results. The inclusion of the volatility terms in the mean equation allows us to reflect on Friedman's [3] hypothesis as well.

Ω_t indicates all relevant information known at time t, and Σ_t is the time-varying covariance matrix defined below. The diagonal elements of the (2×2) covariance matrix are given by

$$\ln(\sigma^2_{\pi,t}) = \gamma_{\pi,0} + \gamma_{\pi,1} f_1(z_{\pi,t-1}) + \gamma_{\pi,2} f_2(z_{\Delta y,t-1}) + \gamma_{\pi,3} \ln(\sigma^2_{\pi,t-1}), \tag{4}$$

$$\ln(\sigma^2_{\Delta y,t}) = \gamma_{\Delta y,0} + \gamma_{\Delta y,1} f_1(z_{\pi,t-1}) + \gamma_{\Delta y,2} f_2(z_{\Delta y,t-1}) + \gamma_{\Delta y,3} \ln(\sigma^2_{\Delta y,t-1}). \tag{5}$$

In Eqs. (4) and (5), f_1 and f_2 are functions of standardized innovations. These innovations are defined as $z_{\pi,t} = \varepsilon_{\pi,t}/\sigma_{\pi,t}$ and $z_{\Delta y,t} = \varepsilon_{\Delta y,t}/\sigma_{\Delta y,t}$. The functions f_1 and f_2 capture the effect of sign and the size of the lagged innovations as

$$f_1(z_{\pi,t-1}) = |z_{\pi,t-1}| - E(|z_{\pi,t-1}|) + \delta_\pi z_{\pi,t-1} \tag{6}$$

$$f_2(z_{\Delta y,t-1}) = |z_{\Delta y,t-1}| - E(|z_{\Delta y,t-1}|) + \delta_{\Delta y} z_{\Delta y,t-1}. \tag{7}$$

The first two terms in Eqs. (6) and (7) capture the size effect and the third term measures the sign effect. If δ is negative, a negative realization of z_{t-1} will increase the volatility by more than a positive realization of equal magnitude. Similarly, if the past absolute value of z_{t-1} is greater than its expected value, the current volatility will rise. This is called the leverage effect and is documented by Black [20] and Nelson [18], among others.

To complete the specification of Σ_t in Eq. (3), we need to focus on the off-diagonal elements. The off-diagonal elements of the covariance matrix Σ_t are defined in a manner similar to that in [21]. The key is to define a time-varying conditional correlation which when combined with the conditional variances given Eqs. (4) and (5) generates the required conditional covariance. The conditional correlation is allowed to depend on the lagged standardized innovations and is transformed using a suitable function so that it lies in the range $(-1, 1)$. This is given by the following equation:

$$\sigma_{j,I,t} = \rho_{j,I,t}\sigma_{j,t}\sigma_{I,t}, \quad \rho_{j,I,t} = 2\left(\frac{1}{1+\exp(-\xi_t)}\right) - 1, \quad \xi_t = c_0 + c_1 z_{j,t-1} z_{I,t-1} + c_2 \xi_{t-1}. \tag{8}$$

Although the function ξ_t may be unbounded, the exponential function transformation will restrict it to the desired range for correlation.

Based on the above description of the variance structure of the bivariate system, the asymmetric effect of standardized innovations on volatility may be measured as the derivatives from Eqs. (6) and (7):

$$\partial f_i(z_{i,t})/\partial z_{i,t} = \begin{pmatrix} 1+\delta_i & z_i > 0 \\ -1+\delta_i & z_i < 0 \end{pmatrix}. \tag{9}$$

Relative asymmetry is defined as $|-1+\delta_i|/(1+\delta_i)$. This quantity is greater than, equal to, or less than 1 for negative asymmetry, symmetry, and positive asymmetry, respectively.

The persistence of volatility may also be quantified by an examination of the half-life (HL), which indicates the time period required for the shocks to reduce to one half of their original size:

$$\mathrm{HL} = \frac{\ln(0.5)}{\ln|\gamma_{i.3}|}. \tag{10}$$

[5] Hamilton identified the following dates as being associated with an exogenous decline in the world petroleum supply: November 1956 → 10.1%, November 1973 → 7.8%, December 1978 → 8.9%, October 1980 → 7.2%, August 1990 → 8.8%, other periods → 0%.

Table 1A
Summary statistics.

	Mean	Standard deviation	Skewness	Kurtosis	Normality (Bera–Jarque test)
π	4.00	4.21	0.54	3.92	51.18 (0.00)
Δy	3.00	10.23	−0.04	8.39	730.30 (0.00)

Table 1B
Test for serial correlation.

	Q(4)	Q(12)	$Q^2(4)$	$Q^2(12)$
π	331.23 (0.00)	992.81 (0.00)	132.55 (0.00)	149.34 (0.00)
Δy	151.50 (0.00)	167.95 (0.00)	94.57 (0.00)	108.01 (0.00)

Table 1C
Unit root test.

	ADF		PP		KPSS	
	C	*C* & *T*	*C*	*C* & *T*	*C*	*C* & *T*
π	−2.18	−2.18	−20.46***	−20.08***	0.50*	0.48*
Δy	−5.24***	−5.33***	−16.86***	−16.86***	0.07***	0.04***
σ_π	−3.75***	−3.81**	−5.54***	−5.58***	0.17***	0.13***
$\sigma_{\Delta y}$	−3.53***	−3.96**	−5.88***	−6.68***	1.02	0.10***

Note: (i) Figures in parentheses are the probabilities. (ii) *C* and *T* denote use of a constant and a time trend in these tests.
* Implies significance at 10% level.
** Implies significance at 5% level.
*** Implies significance at 1% level.

For a given pair of series for the inflation and the growth rate of output together with the covariance specification, the parameters (28) to be estimated may be conveniently labelled as

$$\Theta \equiv \begin{Bmatrix} \alpha_\pi, \beta_{\pi,1}, \beta_{\pi,2}, \beta_{\pi,3}, \beta_{\pi,4}, \beta_{\pi,5}, \beta_{\pi,6}, \beta_{\pi,7}, \gamma_{\pi,0}, \gamma_{\pi,1}, \gamma_{\pi,2}, \gamma_{\pi,3}, \delta_\pi, \\ \alpha_{\Delta y}, \beta_{\Delta y,1}, \beta_{\Delta y,2}, \beta_{\Delta y,3}, \beta_{\Delta y,4}, \beta_{\Delta y,5}, \beta_{\Delta y,6}, \gamma_{\Delta y,0}, \gamma_{\Delta y,1}, \gamma_{\Delta y,2}, \gamma_{\Delta y,3}, \delta_{\Delta y} \\ c_0, c_1, c_2 \end{Bmatrix}. \tag{11}$$

The estimation of these parameters is achieved by numerical maximization of the joint likelihood function under the distributional assumption of this model. If the sample size is T then the log-likelihood function to be maximized with respect to the parameter set Θ is

$$L(\Theta) = -T\ln(0.5\pi) - 0.5\sum_{t=1}^{T}\ln|\Sigma_t| - 0.5\sum_{t=1}^{T}\begin{bmatrix}\varepsilon_{\pi,t} & \varepsilon_{\Delta y,t}\end{bmatrix}\Sigma_t^{-1}\begin{bmatrix}\varepsilon_{\pi,t} \\ \varepsilon_{\Delta y,t}\end{bmatrix}. \tag{12}$$

The numerical optimization of the likelihood function is carried out in the Gauss programming environment.

3. Results and discussion

3.1. Summary tables

Table 1A shows the mean, standard deviation, skewness, kurtosis and the normality tests for inflation and output growth. Both inflation and growth failed to satisfy the Bera–Jarque test for normality. Table 1B shows that there is a significant amount of serial dependence in the data. It is also clear from Table 1C that inflation and output growths are both stationary series, and as such are included the model directly.

Table 1C also shows that the estimated inflation uncertainty and growth uncertainty series are both stationary.

3.2. Estimated bivariate EGARCH dynamics

Table 2 reports the estimates of the parameters describing the mean, the variance and the correlation function of the joint system. In the mean equation of inflation, $\beta_{\pi,1}$ and $\beta_{\pi,2}$ (coefficient of past inflation) are positive and significant, suggesting that past inflation increases present inflation significantly. The estimated coefficients $\beta_{\pi,5}$ (coefficient of inflation uncertainty) and $\beta_{\pi,7}$ (coefficient of the oil price dummy) are also found to be significant. The positive estimate of $\beta_{\pi,5}$ implies that inflation uncertainty increases the level of inflation significantly. This supports Friedman's [3] hypothesis. On the other hand, output uncertainty has no significant effect on inflation but the oil price has a positive and significant effect on inflation.

Similarly, from the mean equation of output growth, it can be seen that the estimate of $\beta_{\Delta y,5}$ (coefficient of inflation uncertainty) is negative and significant. Therefore, inflation uncertainty lowers the growth significantly for the US. Similarly, the insignificant estimated value of $\beta_{\Delta y,6}$ (coefficient of growth uncertainty) indicates that growth uncertainty itself has no effect on growth in the US. To summarize these observations, the inflation uncertainty increases inflation and decreases

Table 2
Parameter estimates for the bivariate EGARCH model with dynamic correlation inflation and output growth rate.

	Inflation			Output
Mean equation				
α_π	0.00909 (1.03)	$\alpha_{\Delta y}$		0.01607 (1.13)
$\beta_{\pi,1}$	0.22355*** (7.07)	$\beta_{\Delta y,1}$		0.01389 (0.48)
$\beta_{\pi,2}$	0.07775* (1.96)	$\beta_{\Delta y,2}$		0.02736 (1.09)
$\beta_{\pi,3}$	−0.01524 (−0.71)	$\beta_{\Delta y,3}$		0.23848*** (5.54)
$\beta_{\pi,4}$	0.03175 (1.61)	$\beta_{\Delta y,4}$		0.16307*** (4.25)
$\beta_{\pi,5}$	0.25060** (1.98)	$\beta_{\Delta y,5}$		−0.18215*** (−3.35)
$\beta_{\pi,6}$	−0.05455 (−0.90)	$\beta_{\Delta y,6}$		0.13916 (0.94)
$\beta_{\pi,7}$	0.03889*** (7.44)			
Variance equation				
$\gamma_{\pi,0}$	−0.20034*** (−14.39)	$\gamma_{\Delta y,0}$		−0.38867*** (−8.89)
$\gamma_{\pi,1}$	0.30499*** (7.55)	$\gamma_{\Delta y,1}$		−0.02338 (−0.64)
$\gamma_{\pi,2}$	−0.03866 (−1.30)	$\gamma_{\Delta y,2}$		0.26086*** (5.40)
$\gamma_{\pi,3}$	0.96196*** (560.69)	$\gamma_{\Delta y,3}$		0.91903*** (102.48)
δ_π	0.36093*** (2.82)	$\delta_{\Delta y}$		−0.63832*** (−4.60)
Correlation function				
c_0			−0.06461 (−0.43)	
c_1			−0.03169 (−1.24)	
c_2			−0.92285*** (−160.25)	
Half-life	17.87			8.21
Relative asymmetry	0.47			4.53

The numbers in parentheses indicate t-statistics. Half-life represents the time it takes for the shocks to reduce their impact by one half. The relative asymmetry may be greater than, equal to, or less than 1, indicating negative asymmetry, symmetry, and positive asymmetry, respectively.
* Implies significance at 10% level.
** Implies significance at 5% level.
*** Implies significance at 1% level.

Table 3
Diagnostics tests (US inflation and output growth rate).

p-values for Ljung–Box $Q(20)$ statistics	Inflation	Output
z	0.019	0.015
z^2	0.742	0.770
$z_1.z_2$	0.999	
p-values for Engle and Ng [22] diagnostic tests		
Sign bias test	0.532	0.482
Negative size bias test	0.910	0.629
Positive size bias test	0.130	0.836
Joint test	0.379	0.576

z represents the standardized residual for the corresponding equation, i.e. either inflation or output growth rate.
$z_1.z_2$ indicates the product of the two standardized residuals. The entries are the p-values for the relevant hypothesis tests.

growth significantly and growth uncertainty has no effect on inflation or growth. The findings contradict the findings of Shields et al. [14] and Grier et al. [7].[6]

The estimates of the variance equations for both inflation and output growth show that these are time varying, display asymmetry and exhibit statistically significant EGARCH terms. The persistence in volatility is measured by the parameters $\gamma_{\pi,3}$ and $\gamma_{\Delta y,3}$. The values of these two parameters are less than one for both equations, which is a necessary condition for the volatility process to be stable. We have indicated this fact earlier from the plots in Fig. 1. The magnitude of these persistence parameters suggests the tendency for the volatility shocks to persist. Using the HL parameter, the volatility persistence can be expressed in monthly terms. It appears that the persistence in volatility for inflation (17.87 months) is nearly double that of output growth (8.21 months).

Together with the estimates of the variance equations for both inflation and output growth, we also have estimates of the terms defining time-varying correlations between these two variables. The statistical significance of the persistence term for the correlation structure indicates that a constant correlation model would be inappropriate. High realized correlation (Fig. 1) tends to coincide with the high output growth volatility over the sample period. This obviously includes the period of the first oil price shock.

Another interesting finding is that of relative asymmetry. This is indicative of the likely response of the conditional uncertainty based on the sign of the innovation of the previous period. For inflation it is lower than 1, which indicates

[6] Grier et al. [7] and Shields et al. [14] find that inflation uncertainty lowers, rather than increases, average inflation for the US. Using univariate GARCH modelling, Kontonikas [9] finds that inflation uncertainty has a positive but insignificant effect on inflation for the UK.

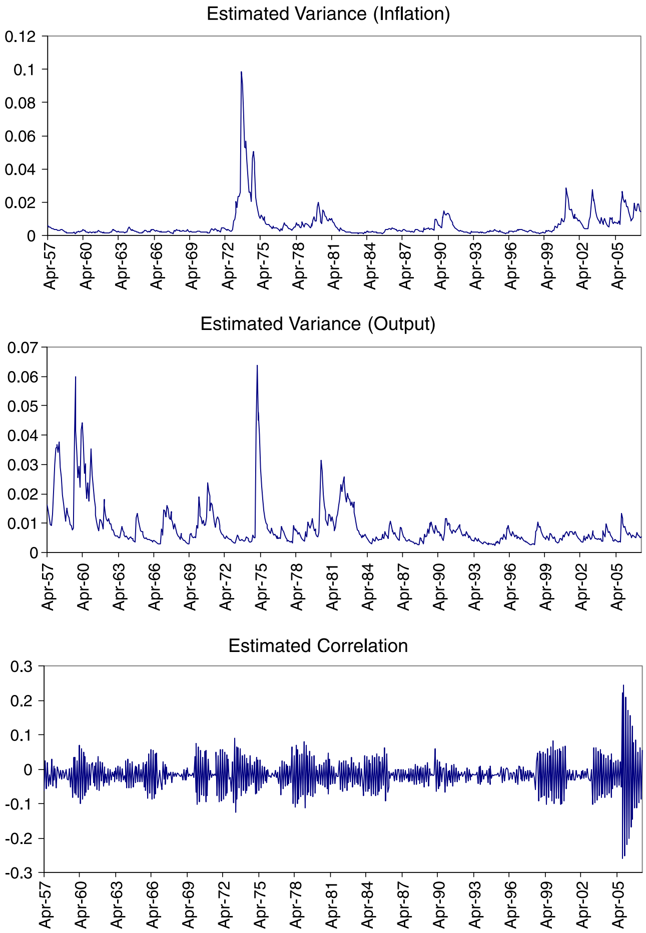

Fig. 1. Estimated variance series for the US.

Table 4
Bivariate Granger causality test results.

Direction of causality	Lag-4	Lag-8	Lag-12
$\Delta y \rightarrow \pi$	(+) 2.04*	(+) 1.15	(+) 1.21
$\pi \rightarrow \Delta y$	(−) 0.64	(−) 1.75*	(−) 1.63*
$\Delta y \rightarrow \sigma_\pi$	(−) 0.22	(−) 0.29	(−) 0.58
$\sigma_\pi \rightarrow \Delta y$	(−) 3.58***	(−) 2.13**	(−) 2.13**
$\pi \rightarrow \sigma_\pi$	(+) 57.83***	(+) 29.94***	(+) 19.95***
$\sigma_\pi \rightarrow \pi$	(+) 6.11***	(+) 3.63***	(+) 3.28***
$\Delta y \rightarrow \sigma_{\Delta y}$	(−) 87.25***	(−) 41.42***	(+) 27.87***
$\sigma_{\Delta y} \rightarrow \Delta y$	(+) 5.49***	(+) 4.02***	(−) 2.80***

Note: (i) $\Delta y \rightarrow \pi$ implies that economic growth Granger-causes inflation. (ii) Here, π = inflation (calculated using PPI); Δy = industrial production growth; σ_π = inflation uncertainty and $\sigma_{\Delta y}$ = growth uncertainty.

* Implies significance at 10% level.
** Implies significance at 5% level.
*** Implies significance at 1% level.

that negative innovation in the previous period results in lower conditional uncertainty in the current period. For output growth, however, a negative innovation in the past period implies a higher conditional uncertainty in the current period. The use of the EGARCH model helps us explore such intricate structure in the conditional volatility of the two variables.

3.3. Diagnostic tests

The diagnostics statistics for the model are given in Table 3. The test statistics include the 20th-order serial correlation in the level and squared standardized innovations as well as the asymmetry test statistics following Engle and Ng [22]. The Ljung–Box statistics indicate the absence of linear and nonlinear dependence in the standardized innovations for the sample period examined. The Engle and Ng test confirms the validity of the Ljung–Box test. This confirms that there are no

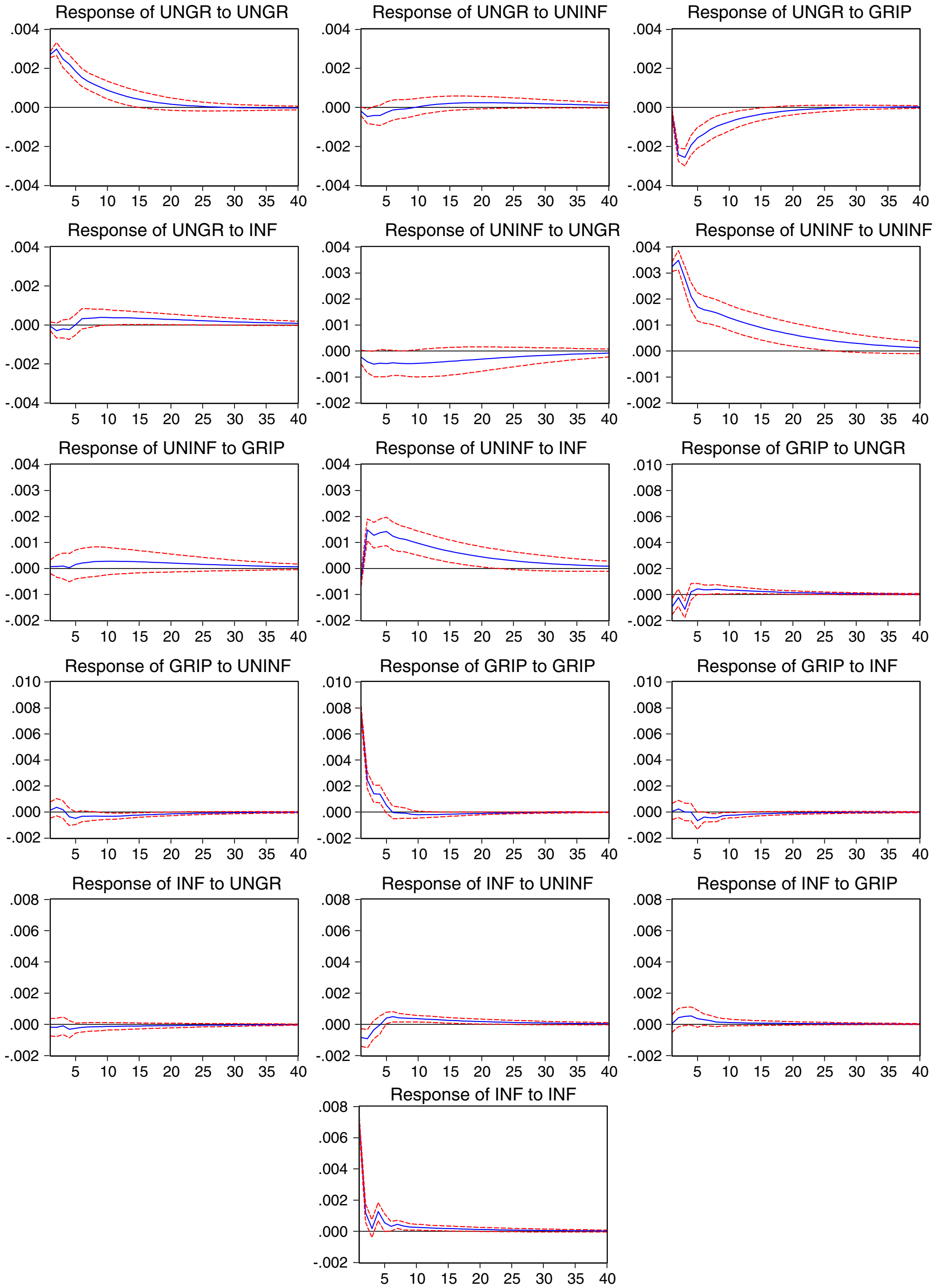

Fig. 2. Generalized impulse response functions: response to generalized one standard deviation innovations ±2 S.E. Notes: INF = Inflation; UNINF = Inflation Uncertainty; GRIP = Growth of Industrial Production and UNGR = Growth Uncertainty.

sign biases, that is, there is no asymmetry effect. This bias could potentially affect the outcomes of the Ljung–Box test. We are thus comfortable with the outcomes of the test. Besides, the joint test bias can be rejected at the 90% confidence level. The Engle and Ng test supports a good fit of the bivariate EGARCH model to the available data set.

3.4. Granger causality tests

Granger causality test results are presented in Table 4 for different lag periods. Granger causality test results are mostly consistent with the findings obtained using bivariate EGARCH modelling. We find that inflation uncertainty Granger-causes output growth and the sum of the lagged coefficients is negative. We also find that inflation Granger-causes inflation uncertainty and vice versa, and the sums of the lagged coefficients for both directions are positive. Similarly, Granger causality exists between growth and growth uncertainty and vice versa, but the signs of the lagged coefficients are positive and negative for different lag structures.

3.5. Generalized impulse response analysis

In this section, we further investigate the statistical significance of innovations of the variables under study by using Generalized Impulse Response Functions (GIRFs), introduced by Pesaran and Shin [23]. We have estimated GIRFs by employing VAR (Vector Auto-Regression), consisting of inflation, inflation uncertainty, growth and growth uncertainty. The number of lags is determined by AIC (Akaike Information Criterion). The impulse response results are presented in Fig. 2. Dashed lines indicate two standard error (S.E.) bands representing a 95% confidence region.

Fig. 2 shows that the innovation in output growth does not explain the movements of growth uncertainty and inflation uncertainty, but does explain the movement of inflation significantly only for a short period of time. Inflation uncertainty increases inflation uncertainty further and has a long-lasting effect. Inflation also increases inflation uncertainty significantly. The innovation in growth uncertainty significantly and negatively explains the movements of growth only. However, the innovation of inflation uncertainty has a long-lasting (approximately up to 23 months) significant negative effect on the movements of inflation.

4. Concluding remarks

In this study, we have investigated the relation between inflation, output growth, inflation uncertainty, and output growth uncertainty using bivariate EGARCH modelling for the US. We conclude that inflation uncertainty increases inflation and reduces growth significantly. However, output growth uncertainty has no significant effect on inflation or output growth. The oil price, on the other hand, significantly affects inflation.

The findings of this study strongly support Friedman's [3] hypothesis. But the results in general contradict the findings of similar studies by Shields et al. [14] and Grier et al. [7], where inflation uncertainty is found to reduce the level of inflation. These results are also substantiated by using Granger causality and GIRFs.

It is clear from the bivariate EGARCH modelling and GIRFs that inflation increases inflation uncertainty and inflation uncertainly further increases inflation uncertainty significantly and has a long-lasting effect. Inflation uncertainty which increases inflation further and reduces growth is potentially harmful for the economy. The oil price has a significant positive influence on inflation. Therefore, it is clear from this study that inflation itself is not good for the US economy. From the policy perspective, the US authorities should attempt to keep inflation stable and low. Since the oil price also affects inflation, the US policy makers should stabilize the domestic oil price through subsidization and thus keep inflation low and thus help boost investment, employment and growth. The optimal rate of inflation is difficult to obtain, and is a potential research question to be pursued.

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