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INFLATION, INFLATION UNCERTAINTY AND GROWTH IN THE IRANIAN ECONOMY: AN APPLICATION OF BGARCH-M MODEL WITH BEKK APPROACH

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Abstract. This paper investigates the relationship between inflation, economic growth and their respective uncertainties in Iran for the period of 1988–2008 by using quarterly data. We employ a Bivariate Generalized Autoregressive Conditional Heteroskedasticity-in-Mean (BGARCH-M) model to examine in a unified empirical framework all the possible interactions between inflation uncertainty and growth in Iran. The model is simultaneously estimated by using the maximum log-likelihood method with the BEKK approach. The main findings of the present study are: (1) Inflation causes inflation uncertainty, supporting the Friedman-Ball hypothesis. (2) Inflation uncertainty affects the level of economic growth, supporting the Friedman (1977) hypothesis. (3) Growth uncertainty does not affect the level of economic growth, supporting the Friedman (1968) hypothesis. (4) And finally our empirical evidence shows that growth uncertainty affects the level of inflation, supporting the Deveraux (1989) hypothesis.

Keywords: inflation uncertainty, growth uncertainty, BGARCH-M, BEKK approach, Iran.

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1. Introduction

In the last two decades, there has been an increasing interest in empirical research relating to economic growth in the case of Iran. In recent years a few papers constructed a large set of possible explanatory variables and employed econometric techniques to identify the variables which have a statistically significant impact on economic growth of Iran (Moshiri, Jahangard 2004; Mohammadi, Akbari Fard 2008; Komijani, Nazari 2009). However, studying the impact of inflation uncertainties on real income growth in the close economy of Iran deserves attention from researchers.

Heidari and Yengjeh (2010), Heidari *et al.* (2010), and Heidari and Bashiri (2011) consider uncertainty in their studies with the Iranian data. In these studies, they all employ Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models and proxied inflation and output uncertainty by the conditional variance of shocks to inflation and output growth, respectively. GARCH models have been extensively employed in the studies for stock markets as well (Teresiene 2009). Results of Heidari and Yengjeh (2010) suggest no significant relationship between inflation uncertainty and real growth. Moreover, results of Heidari *et al.* (2010) reveal that growth uncertainty does not affect the level of economic growth, while Heidari and Bashiri (2011) show that growth uncertainty affects the level of inflation. The most important drawback of these studies is that, they have used a univariate GARCH specification for estimation of the uncertainties. Univariate models do not allow studying the joint determination of more than one series. There is a vast theoretical literature that emphasizes the importance of simultaneous effects of inflation and growth uncertainty on economic growth (Friedman 1968; Friedman 1977; Black 1987; Deveraux 1989; Holland 1993).

There is a lot of empirical evidence in the literature, which address this issue by applying bivariate models. For example, Grier *et al.* (2004) and Shields *et al.* (2005), by using a Bivariate GARCH (BGARCH) model, find that inflation uncertainty decreased inflation and output growth for the US, but output uncertainty increased growth but reduced inflation. Karanasos and Kim (2005) employ a BGARCH model of inflation and output growth to investigate the relationship between nominal and real uncertainty in the G3. They find that for the entire sample period 1957–2000, in all three countries, there is no causal relationship between nominal and real uncertainty. Moreover, they find different results (causal direction) for these three countries in different sub-samples. Narayan *et al.* (2009) use the EGARCH model to examine the relationship among output, inflation and their respective uncertainties for China. Their results suggest that Chinese output-inflation behaviour is consistent with the hypothesis that increased inflation uncertainty lowers average inflation; the hypothesis that inflation volatility reduces economic growth and the hypothesis that higher output volatility increases economic growth. They also find no support for the Deveraux (1989) hypothesis that output uncertainty has a positive impact on the level of inflation. Bhar and Mallik (2010) show that inflation uncertainty has positive and significant effect on the level of inflation and a negative and significant effect on the output growth. Their results, however, reveal that output uncertainty has no significant effect on output growth or inflation. Conrad *et al.* (2010) by using a BGARCH model find that inflation has a positive impact on both inflation and growth uncertainties. Their results also show that not only uncertainty of inflation and growth affect the level of inflation and growth but the level of inflation and growth affect their respective uncertainties.

To the best of our knowledge, there isn't any empirical study on assessing the relationship between inflation, economic growth and their respective uncertainties in the case of the Iranian data. However, this relationship with other countries' data has been mixed (Grier, Perry 2000; Fountas *et al.* 2006; Jiranyakul, Opiela 2010; Bhar, Mallik 2010; Conrad *et al.* 2010).

Our purpose in this paper is to investigate the relationship between the conditional means and conditional variance of inflation and output growth in Iran. Our main model for explaining the conditional means of the two series is a VAR (Vector Autoregressive) type GARCH-M (VAR-GARCH-M) model. We simultaneously estimate a time-varying variance-covariance matrix. As the conditional variance is just the variance of the one step ahead forecasting error, the GARCH model seems like a natural choice to study the effects of uncertainty. The multivariate GARCH-M approach has the advantage that one estimates the uncertainty measure and its effects together in a simultaneous model. The rest of the paper is structured as follows. Section 2 provides a brief theoretical background; section 3 outlines the econometric model; section 4 defines the data; section 5 presents and interprets the main results; and finally, section 6 concludes the paper.

2. Theoretical background

Economic theory can predict either a positive, negative or zero effect of inflation on output growth, depending on the specific assumptions of the model (Tobin 1965; Stockman 1981; Sidrauski 1967). Some papers (Gomme 1993; Jonees, Manuelli 1995) use endogenous growth models and find a negative growth effect of inflation. However, there is another theoretical link between inflation and economic growth. The well-known hypothesis is from Friedman (1977) who argues that high inflation leads to more inflation uncertainty, and this uncertainty lowers economic efficiency and reduces output. Ball (1992), using a game theoretical framework, shows a formal derivation of Friedman's hypothesis that higher inflation causes more inflation uncertainty. Cukierman and Meltzer (1986), using Barro and Gordon (1983) model, predict that higher inflation uncertainty leads to more inflation. Holland (1995) argues that, in the presence of a stabilization motive on the policymaker, an increase in inflation uncertainty will invite a tight monetary policy response and a lower average inflation rate. Hence, Holland (1995) concludes that higher inflation uncertainty leads to less inflation rate. Dotsey and Sarte (2000), using a Cash-in-advance model, show that inflation variability has a positive effect on economic growth. They argue that risk averse agents will tend to save more during periods of uncertainty. This extra savings will then translate via higher investment into higher economic growth. Black (1987) describes that the choice of investing in a risky specialized technology will produce an economy with higher average growth. In other words, he argues that greater output growth uncertainty raises the average real growth rate. Deveraux (1989) extended Barro and Gordon (1983) model to show that output growth uncertainty can positively affect inflation.

The common feature of these apparently unrelated arguments is the systematic connection between inflation and economic growth and their respective uncertainties. To estimate these relationships simultaneously, we apply a BGARCH-in-Mean (BGARCH-M) model of output growth and inflation. In the applied BGARCH-M models, the dependent variables in the mean equations are inflation and output growth. The explanatory variables will contain variables that help to forecast growth and inflation in mean equations and their uncertainty measures in variance equations. Thus, the hypotheses that we are going to test with Iranian data are as follows:

– Is there a significant relationship between inflation and inflation uncertainty?
– Does inflation uncertainty reduce economic growth?
– Does economic growth uncertainty have any influence on the level of economic growth?
– Does economic growth uncertainty affect inflation?

3. The model

Since Engle's (1982) paper, the ARCH model has become a popular methodology for assessing Friedman's hypothesis. Its popularity can be attributed to its ability to generate time varying measure of inflation and output uncertainty (Wilson 2006). The GARCH model of inflation and growth, which estimate the mean and variance equations jointly for each series, can be written as follows:

$$\pi_t = \mu_1 + \sum_{i=1}^{m} \phi_i \pi_{t-i} + \sum_{i=1}^{m} \theta_i y_{t-i} + \varepsilon_{1,t}, \tag{1}$$

$$h_{1,t} = c_1 + a_1 \varepsilon_{1,t-1}^2 + b_1 h_{1,t-1}, \tag{2}$$

$$y_t = \mu_2 + \sum_{i=1}^{m} \phi_i \pi_{t-i} + \sum_{i=1}^{m} \theta_i y_{t-i} + \varepsilon_{2,t}, \tag{3}$$

$$h_{2,t} = c_2 + a_2 \varepsilon_{2,t-1}^2 + b_{21} h_{2,t-1}, \tag{4}$$

where π_t, y_t denote the rate of inflation, and GDP growth, respectively. The residuals, $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$, are assumed to be normally distributed with a time varying conditional variances. $h_{1,t}$ is the conditional variance of the residual term taken as inflation uncertainty at time t and $h_{2,t}$ is the conditional variance of the residual term taken as growth uncertainty at time t. Equations (1) and (3) are the autoregressive representation of inflation and growth, and equations (2) and (4) are the GARCH (1, 1) representation of conditional variance (Heidari, Bashiri 2010, 2011).

The univariate volatility models have a limitation which is assumed that the conditional variance of each series is independent from all other series. This could be a significant limitation as there could be volatility spilovers between variables, which makes the univariate model misspecified. Moreover, the covariances between series also are of interest. The BGARCH models can potentially overcome these deficiencies of their univariate counterparts. In addition, there are many situations when empirical multivariate models of conditional heteroscedasticity can be used fruitfully (Brooks 2002).

BGARCH models are very similar to their univariate counterparts, except that the former also specify equations for how the covariance moves over time. Several different BGARCH formulations have been proposed in the literature, including the VECH, diagonal VECH and the BEKK approaches. This paper, however, employs BEKK approach. It is assumed that in each model, for simplicity, there are two variables, whose return variance and covariance are to be modelled.

To illustrate the BEKK approach, consider the following equation:

$$H_t = C_0^{/}C_0 + A_{11}^{/}\varepsilon_{t-1}\varepsilon_{t-1}^{/}A_{11} + B_{11}^{/}H_{t-1}B_{11},$$
$$\varepsilon_t \mid \psi_{t-1} \approx N(0, H_t), \tag{5}$$

where H_t is a 2×2 conditional variance-covariance matrix that is always positive definite, ε_t is a 2×1 innovation (disturbance) vector, ψ_{t-1} represents the information set at time $t-1$, C is a diagonal 2×2 lower triangular matrix of parameters, A and B are 2×2 matrices. The model requires the estimation of 11 parameters (C has 3 elements, A and B each have 4 elements). In order to gain a better understanding of how the BEKK approach works, the elements are written out below:

$$H_t = \begin{bmatrix} h_{11t} & h_{12t} \\ h_{21t} & h_{22t} \end{bmatrix},\ \varepsilon_t = \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix},\ C = \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix},\ A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix},\ B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}. \tag{6}$$

We see that this model economizes on parameters by imposing restrictions both across and within equations.

The diagonal BEKK model, takes A and B as diagonal matrices. For this case, the BEKK model is a restricted version of the VEC model with diagonal matrices (Franke *et al.* 2005).

The diagonal BEKK model is given by the following equations:

$$h_{11,t} = c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + b_{11}^2 h_{11,t-1}, \tag{7}$$

$$h_{22,t} = c_{21}^2 + c_{22}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + b_{22}^2 h_{22,t-1}, \tag{8}$$

$$h_{12,t} = h_{21,t} = c_{11}c_{21} + b_{11}b_{22}h_{12,t-1} + a_{11}a_{22}\varepsilon_{1,t-1}^2\varepsilon_{2,t-1}^2. \tag{9}$$

Under the assumption of conditional normality, the parameters of the BGARCH models of BEKK specifications can be estimated by maximizing the following log-likelihood function:

$$l(\theta) = -\frac{TN}{2}\log 2\pi - \frac{1}{2}\sum_{t=1}^{T}(\log|H_t| + \varepsilon_t^{/}H_t^{-1}\varepsilon_t), \tag{10}$$

where θ denotes all the unknown parameters to be estimated, N is the number of series in the system and T is the number of observations and other notations are defined before. The maximum likelihood estimate for θ is asymptotically normal, and thus traditional procedures for statistical inference are applicable.

4. Data

In our empirical analysis we use the Consumer Price Index (CPI) and the real Gross Domestic Product (GDP) at 1996 constant prices for Iran as proxies for the price level and output, respectively. The data have quarterly frequency and range from 1988:Q1 to 2008:Q4 as gathered from the Central Bank of Iran (2011). Inflation is measured by the difference of the log of CPI (Asteriou 2006):

$$\pi_t = (\ln \mathrm{CPI}_t - \ln \mathrm{CPI}_{t-1}) \times 400. \tag{11}$$

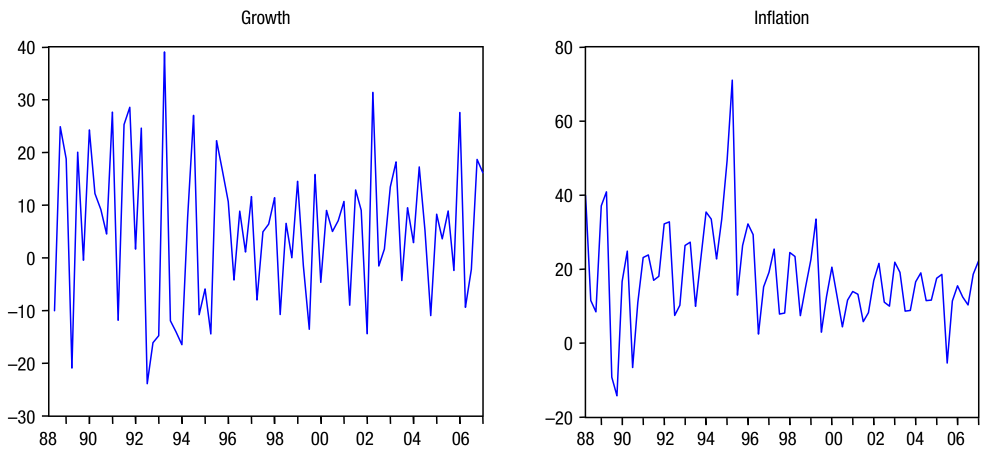

Fig. 1. Inflation and Growth Rate in the Iranian Economy

Real output growth (here after growth) is measured by the quarterly difference in the log of the GDP:

$$y_t = (\ln \mathrm{GDP}_t - \ln \mathrm{GDP}_{t-1}) \times 400. \quad (12)$$

Figure 1 shows the inflation and growth rate in the Iranian economy during 1988–2008.

As Figure 1 shows the Iranian economy has experienced volatile inflation and growth rate during last three decades. The summary statistics for the data is given in Table 1. The large value of the Jargue-Bera statistic for inflation implies a deviation from normality. The value of the Jargue-Bera statistic for growth variable implies that, it is normally distributed.

Table 1. Summary Statistics for Iranian Inflation and Growth

	Inflation	Growth
Mean	17.9419	5.26218
Median	16.7609	6.41796
Maximum	71.0550	39.0916
Minimum	–14.2872	–23.8725
Std. Dev.	13.0538	14.0937
Skewness	0.82163	0.07409
Kurtosis	5.84904	2.30495
Jargua-Bera	34.25522	1.57828
Probability	0.0000	0.454233

The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP)[1] Unit Root Tests are employed to test the integration level and the possible long-run relationship among the variables (Dickey, Fuller 1981; Phillips, Perron 1988). The PP procedures compute a residual variance, which is robust to auto-correlation, and are applied to test for unit roots as an alternative to the ADF unit root test (Katircioglu 2009).

To confirm the test results obtained from the ADF and PP tests, two more tests for unit roots have been employed in the present study, Firstly, *Kwiatkowski, Phillips, Schmidt, and Shin's* test (*KPSS*) (1992) is suggested to eliminate a possible low power against stationary near unit root processes which occurs in the *ADF* and PP tests. The KPSS test complements the ADF and PP tests in which the null hypothesis of KPSS test is that a series is stationary. This means that a stationary series is likely to have insignificant KPSS statistics and significant ADF and PP statistics.

The unit root test results reveal that both inflation and growth series are stationary at their levels[2]. As standard unit root tests, such as ADF, PP, and KPSS tests are biased towards the null of unit root in the presence of structural breaks on one hand, and visual inspection of the series in Figure 1 implies the existence of possible structural breaks on the other hand, we apply the endogenously determined multiple break tests introduced and applied by Bai and Perron (1998, 2003)[3]. Our results show that using most of these tests, we have no break in the mean of the series under consideration. However, we use Lee and Strazicich (2003) test to test the null hypothesis that the series under consideration has unit root against the alternative of stationary with two endogenous structural breaks[4]. The results reveal that in the presence of two possible structural breaks, the null of unit root for the series are rejected at 1 percent level of significance[5].

5. Estimates

We use a BGARCH model to simultaneously estimate the conditional means, variances, and covariances of inflation and growth. The first step to model a BGARCH model is specifying the mean equation by testing for serial dependence in the data under con-

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[1] As also mentioned by Katircioglu (2009), PP approach allows for the presence of unknown forms of autocorrelation with a structural break in the time series and conditional heteroscedasticity in the error term.

[2] The results of unit root tests are available from the authors upon request.

[3] A GAUSS algorithm to carry out these tests can be downloaded freely from Pierre Perron's homepage at http://econ.bu.edu/perron.

[4] A GAUSS algorithm to carry out this test can be downloaded freely from Junsoo Lee's homepage at http://cba.ua.edu/~Jlee/gauss.

[5] The results of Bai and Perron (1998, 2003) and Lee and Strazicich (2003) unit root test are available from the authors upon request.

sideration. Estimates of the mean equation for inflation rate and growth are based upon the following bivariate model:

$$\begin{bmatrix} \pi_t \\ y_t \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix} + \begin{bmatrix} \phi_1 & \phi_2 \\ \phi_3 & \phi_4 \end{bmatrix} \begin{bmatrix} \pi_{t-1} \\ y_{t-1} \end{bmatrix} + \begin{bmatrix} \theta_1 & \theta_2 \\ \theta_3 & \theta_4 \end{bmatrix} \begin{bmatrix} \pi_{t-2} \\ y_{t-2} \end{bmatrix} + \begin{bmatrix} \rho_1 & \rho_2 \\ \rho_3 & \rho_4 \end{bmatrix} \begin{bmatrix} \sigma_{11} \\ \sigma_{22} \end{bmatrix} + \begin{bmatrix} \nu_t \\ \varepsilon_t \end{bmatrix}. \quad (13)$$

In order to test whether there are any remaining ARCH effects in the residuals, we use the LM test for ARCH in the residuals (see, e.g. Engle 1982). The results of the ARCH-LM test suggest that there is ARCH effect in the residuals. As higher order ARCH indicates persistence in the conditional variance, the model is estimated as a GARCH(1,1) process. The method for the estimation of parameters which we use is maximum log-likehood with BEKK approach[6]. As McAleer (2010) pointed out, between BEKK-GARCH model and its alternative approaches, the final choice should be based on model performance within the appropriate framework in which they are used. From a theoretical perspective, the optimal model for estimating conditional covariance and correlation is the BEKK model (McAleer 2010). Moreover, for the empirical work, the BEKK model is relatively simple in comparison to alternative models, which allows one to achieve reliable estimates of variance and covariances (Minovic 2009; Heidari, Molabahrami 2010). However, we used Constant Conditional Correlation (CCC) and Dynamic CC (DCC) models to estimate the model, and find best results with BEKK approach in terms of in-sample forecasting power. The estimated bivariate BEKK model is reported in Table 2[7].

However, the coefficient of conditional variance of inflation in the mean equation is positive and insignificant, which means that inflation uncertainty does not affect the level of inflation. This result rejects Cukierman and Meltzer (1986), and Cukierman (1992) hypothesis that increases in inflation uncertainty raise the optimal inflation rate by increasing the incentive for the policy maker to create inflation surprises. In other words, our result suggests that inflation causes inflation uncertainty, supporting the Friedman–Ball hypothesis. This result is in line with Fountas (2001), Grier *et al.* (2004), Apergis (2004) and Berument *et al.* (2009).

Moreover, our empirical evidence shows that inflation uncertainty affects the level of economic growth inversely, supporting Friedman (1977) hypothesis. This is inline with Judson and Orphanides (1999), Wilson and Culver (1999), Hayford (2000), Wilson (2006), Hwang (2007) and Fang *et al.* (2009), where they find a negative relationship between inflation uncertainty and output growth for different countries.

Our empirical evidence also shows that growth uncertainty does not affect the level of economic growth, supporting Friedman (1968) hypothesis. Some recent studies including Fountas *et al.* (2004), Fountas and Karanasos (2006), Chatterjee and Shukayev (2006) and Fang *et al.* (2009) find no significant relationship between output growth

[6] Heidari and Molabahrami (2010) explain why the BEKK approach is more convenient among the other specifications of BGARCH models.

[7] An Eviews program to estimate this model is available from the authors upon request.

Table 2. Estimated parameters of bivariate BEKK model

	Coefficient	Std.Error	z–Statistic	Prob
μ_1	14.68156	2.364256	6.209800	0.0000
ϕ_1	0.128723	0.120038	1.072352	0.2836
ϕ_2	20.041729	0.071510	0.583543	0.5595
θ_1	–0.557626	0.086242	–6.465809	0.0000
θ_2	0.143020	0.064076	2.232045	0.0256
ρ_1	0.023359	0.020650	1.131148	0.2580
ρ_2	0.023592	0.008845	2.667355	0.0076
μ_2	10.32378	3.748091	2.754411	0.0059
ϕ_3	–0.138493	0.131560	–1.052697	0.2925
ϕ_4	–0.441259	0.157608	–2.799723	0.0051
θ_3	–0.348366	0.185744	–1.875520	0.0607
θ_4	–0.084866	0.145134	–0.584742	0.5587
ρ_3	–0.030085	0.0012879	2.335898	0.0195
ρ_4	0.007208	0.021703	0.332128	0.7398
c_{11}	3.606652	1.491226	2.418582	0.0156
b_{11}	–0.453760	0.220829	–2.054806	0.0399
a_{11}	0.940544	0.244069	3.853593	0.0001
c_{22}	4.390737	4.367798	1.005252	0.3148
c_{21}	–4.350780	4.153293	–1.047549	0.2948
b_{22}	0.525242	0.286494	1.833345	0.0669
a_{22}	0.762986	0.220164	3.465536	0.0005

and its uncertainty too. Finally, the empirical evidence shows that growth uncertainty affects the level of inflation. This result supports the Deveraux (1989) hypothesis, and is inline with Heidari and Bashiri (2011).

Equation (13) shows that these models allow for dynamic dependence between the volatility of the series under consideration. Figure 2 and 3 show the conditional covariance and variance of inflation and growth. It can be seen from the behavior of conditional covariance (Figure 2) that correlation between inflation and growth is unstable over time.

On the other hand, it has been frequently observed that volatility changes over time. We showed that inflation is more volatile than growth. In the model, estimated conditional variance of inflation has the greatest peak at the time.

Finally we checked the fitted model carefully. For diagnostic checking we used the Ljung-Box statistics of standardized residuals and those of its squared for inflation and growth.

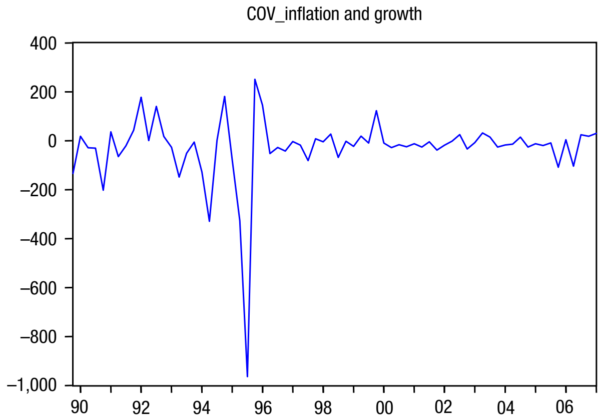

Fig. 2. Estimated conditional covariance for inflation and growth

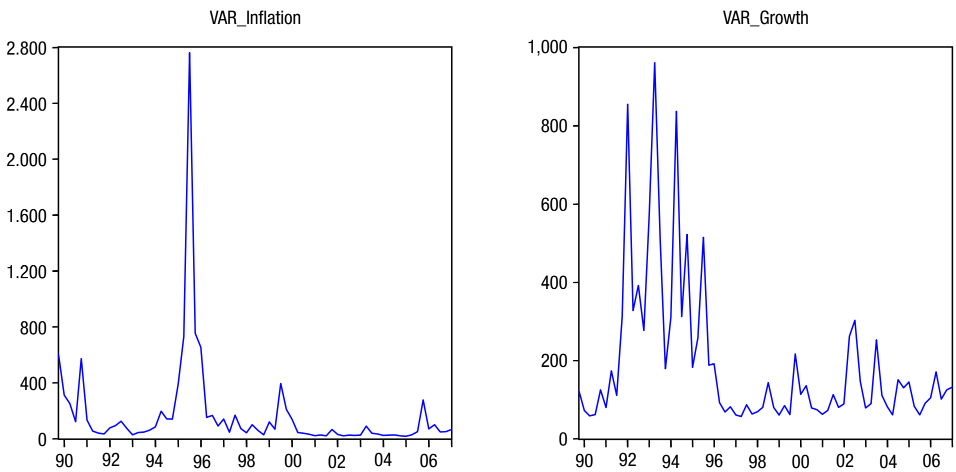

Fig. 3. Estimated conditional variances of inflation and growth

The Q-statistics for checking weather there are any ARCH effects left in the residuals show that autocorrelation is not significant in variance equations for inflation and growth. Thus, the check of the models shows is adequate for describing the conditional heteroscedasticity of the data.

6. Conclusions

In this paper, we have investigated empirically the relationship between inflation, economic growth and their respective uncertainties in Iran. The study has used the period of 1988–2008 by using quarterly data and applying a VAR-type GARCH-M model. The method for the estimation of parameters which we use is maximum log-likelihood with BEKK approach. Our empirical results support a number of important conclusions:

(1) Inflation causes inflation uncertainty, supporting the Friedman-Ball hypothesis. This means that a change in inflation will lead to future expectations for inflation to be less certain in the case of Iran. (2) Inflation uncertainty affects the level of economic growth, supporting Friedman (1977) hypothesis. This also suggests that any uncertainty in future inflation rates will lead to uncertainties in future economic activity and growth rates. (3) Growth uncertainty does not affect the level of economic growth, supporting Friedman (1968) hypothesis. This means that actual economic growth rates are not statistically related to uncertainties about future growth rates. (4) And finally our empirical evidence shows that growth uncertainty affects the level of inflation, supporting Deveraux (1989) hypothesis. This important finding also suggests that uncertainties about the expected volume of economic activity and growth rate in Iran will have influence on inflation rates (leading to rises in inflation) in the economy. The present study has shown that since results are in line and some in contradiction with the other studies, research in searching the relationship between inflation, its uncertainty, and growth is still inconclusive in general and deserves further attention.

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