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Investigation of the relationship between real exchange rate uncertainty and private investment in Iran: An application of bivariate generalized autoregressive conditional heteroskedasticity (GARCH)-M Model with BEKK approach

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This paper investigates the relationship between real exchange rate uncertainty and private investment in Iran for the period of 1988 to 2008 by using quarterly data and applying bivariate generalized autoregressive conditional heteroskedasticity (Bivariate GARCH) model in the Iranian economy. We employ this model to examine in a unified empirical framework the interactions between the variables: first, we are interested to know whether there are bidirectional mean spillovers between real exchange rate and private investment. Second, we want to test if real exchange rate uncertainty has a negative impact on investment as predicted by Dixit and Pindyck (1994). Third, we are going to test if private investment uncertainty reduces the level of private investment. The main findings are that there are bidirectional mean spillovers between real exchange rate and private investment. Real exchange rate uncertainty significantly influences private investment and has a negative effect on it. And finally, our empirical evidence shows that private investment uncertainty affects the level of private investment, negatively.

Key words: Real exchange rate uncertainty, private investment, bivariate generalized autoregressive conditional heteroskedasticity (Bivariate GARCH) model, Iran.

INTRODUCTION

This empirical paper investigates the relationship between real exchange rate uncertainty, as the most important index to macroeconomic instability, and private investment in the Iranian economy. Macroeconomic instability refers to phenomena that decrease the predictability of the domestic macroeconomic environment, leading to resource-allocation distortion and hampering investment and growth (Montiel and Serven, 2004).

The empirical evidence suggests that a competitive and stable macroeconomic environment characterized by low and stable internal and external deficits, low inflation and real depreciation of the exchange rate is conducive to higher growth led by significant private investment (Easterly and Schmidt-Hebbel, 1991). Investment raises the production capacity of the economy and promotes technological progress and makes economic growth faster.

In recent years, there has been increasing interest in empirical research relating to explore the relationship between macroeconomic instability and investment (Serven and Solimano, 1993; Pindyck and Solimano, 1993; Aizenman and Marion, 1993, 1995, 1996; Bleaney, 1996; Ismihan et al., 2005; Ahmed and Qayyum, 2007; Imtiaz and Abdul, 2008; Sanogo and Gyengani, 2008; Kottaridi and Escaleras, 2008).

Theoretical papers in the case of investment under

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uncertainty have a different conclusion about the relationship between them (Hartman, 1972; Abel, 1983; Dixit and Pindyck, 1994; Abel et al., 1996; Lee and Shin, 2000). For example, Dixit and Pindyck (1994) suggested that increased uncertainty reduces investment given the irreversibility of investment projects and, hence, increases the value option of delaying expenditures.

In contrast, Hartman (1972) and Abel (1983) claimed that when the profit function is convex to prices in perfect competition firms, uncertainty will raise the investment. Although, theory predicts that the relationship between exchange rate uncertainty and investment are mixed, depending on assumptions on market competitiveness, risk neutrality, symmetry/asymmetry of investment adjustment costs and entrepreneurial attitudes toward risk (Caballero, 1991; Abel and Eberly, 1994). As Heidari and Pourvaladi (2011) expresses, in developing countries such as Iran in terms of strong economic dependence on crude oil revenue, the issue of exchange rate and its volatility is important.

On the one hand, with real exchange rate decreasing, domestic goods become more expensive than foreign goods and reduce investors export’s income and lead to decrease the private investment. On the other hand, reducing the exchange rate, causes lower prices for imported capital goods, and this makes lower cost for domestic private investors. Moreover, with increasing exchange rate, foreign goods become expensive, this, in turn, reduces consumption and increases the savings as the main source of capital for private investment.

Also, with volatility of real exchange rate, the price mechanism’s efficiency to optimize the allocation of resources will be lost. Our results suggest that the real exchange rate uncertainty is become an impediment to the private investment in Iran.

In the empirical side, there are a lot of empirical investigations about macroeconomic uncertainties and investment with Iranian data in the literature (Gorji and Madani, 2003; Sharifazadeh and Hosseinizadeh Bahreyni, 2003; Daroughe and Mohammadi, 2005; Gaskar et al., 2007; Moradpour et al., 2008; Kazerouni and Doulati, 2008; Maghari, 2009; Heidari and Pourvaladi, 2011). However, in empirical evidences with other countries data, relationship between exchange rate uncertainty and investment are mixed (Cottani et al., 1990; Goldberg, 1993; Serven and Solimano, 1993; Bleaney, 1996; Darby et al., 1999, 2000; Bleaney and Greenaway, 2001; Bohm and Funke, 2001; Serven, 2002, 2003; Byrne and Davis, 2003; Atella et al., 2003; Becker and Hall, 2003; Byrne and Davis, 2003, 2005; Hallett et al., 2004; Barrel et al., 2004; Pradhan et al., 2004; Ruiz and Pozo, 2007; Clause, 2008; Schmidt and Broll, 2009; Heidari and Pouvaladi, 2011), we may conclude that the results of these empirical studies are in line with this general believe that the exchange rate volatility has a negative effect on investment (Bleaney and Greenaway, 2001; Serven, 2002, 2003; Byrne and Davis, 2003, 2005; Ruiz and Pozo, 2007; Clause, 2008; Heidari and Pouvaladi, 2011).

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. This is a remarkable vacuum of study, as there is a vast theoretical literature that emphasizes the importance of simultaneous effects of series (Brooks, 2002; Tsay, 2005; Minović, 2007). And to the best of our knowledge, there is not any empirical study on assessing the relationship between exchange rate, investment and their respective uncertainties with Iranian data.

Our purpose in this paper is to investigate the relationship between the conditional means and conditional variance of real exchange rate and private investment in Iran. Our base model for explaining the conditional means of the two series is a VAR type GARCH-M (VARGARCH-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. Thus the main hypotheses that we are going to test with Iranian data are as follows:

1. There are bidirectional mean spillovers between real exchange rate and private investment.
2. Private investment uncertainty reduces the private investment.
3. Real exchange rate uncertainty affects the private investment.

The rest of the paper is structured as follows. Subsequently, the study outlines our econometric model. Next, it discusses the data. Thereafter, it presents and interprets our main results, and finally, it concludes the paper.

**THE MODEL**

Since ARCH models were introduced by Engle (1982), these models have become the most popular methodology for modelling uncertainty in the financial time series in the form of conditional autoregressive models. Its popularity can be attributed to its ability to generate time varying measures of exchange rate and private investment uncertainties. Followed this, various ARCH models were considered, most of the models were univariate ARCH models.

The univariate volatility models have a limitation that is assumed the conditional variance of each series is independent from all other series. This could be a
significant limitation as there could be volatility spillovers 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).

To estimate the relationships between real exchange rate, private investment and their respective uncertainties simultaneously, we apply a B-GARCH-in-Mean (BGARCH-M) model. In the applied B-GARCH-M models, the dependent variables in the mean equations are real exchange rate and private investment.

The explanatory variables will contain variables that help to forecast real exchange rate and private investment in mean equations and their uncertainty measures in variance equations. The first step to model a B-GARCH model to simultaneously estimate the conditional means, variances, and covariances of variables is specifying the mean equation by testing for serial dependence in the data under consideration.

Estimates of the mean equation for real exchange rate and private investment are based upon the following bivariate model:

\[
\begin{bmatrix}
LPR_{1t} \\
LPR_{2t}
\end{bmatrix} = \begin{bmatrix}
\mu_1 \\
\mu_2
\end{bmatrix} + \begin{bmatrix}
\phi_1 \\
\phi_2
\end{bmatrix} \begin{bmatrix}
LPR_{1,t-1} \\
LPR_{2,t-1}
\end{bmatrix} + \begin{bmatrix}
\rho_1 \\
\rho_2
\end{bmatrix} \begin{bmatrix}
h_{11,t} \\
h_{22,t}
\end{bmatrix} + \begin{bmatrix}
\varepsilon_{1t} \\
\varepsilon_{2t}
\end{bmatrix}
\]

where \( LPR_{1t}, LPR_{2t} \) denote the private investment and real exchange rate, respectively. The residuals, \( \varepsilon_{1t} \) and \( \varepsilon_{2t} \), are assumed to be normally distributed with a time varying conditional variances, which indicate that the mean equation have been effected by innovations at the moment. \( h_{11,t} \) is the conditional variance of the residual term taken as private investment uncertainty at time \( t \) and \( h_{22,t} \) is the conditional variance of the residual term taken as real exchange rate uncertainty at time \( t \). There are several different B-GARCH formulations in the literature, including the Vech, diagonal Vech and the BEKK approaches. This paper, however, employs BEKK approach.

To illustrate the BEKK approach, consider the following equation:

\[
H_t = C + A_1' \varepsilon_{1t} \varepsilon_{1t} + B_1' H_{t-1} B_1
\]

\[
\varepsilon_t | \psi_{t-1} \approx N(0, H_t)
\]

where \( H_t \) is a 2×2 conditional variance-covariance matrix that is always positive definite, \( \varepsilon_t \) is a 2×1 innovation (disturbance) vector, \( \psi_{t-1} \) represents the information set at time \( t-1 \), \( C \) is a diagonal 2×2 lower triangular matrix of parameters, \( A \) and \( B \) as diagonal matrices are 2×2 and they reflect ARCH and GARCH effects of volatility, respectively (Heidari and Bashiri, 2011).

The diagonal BEKK model is given by the following equations:

\[
h_{11,t} = c_{11}^2 + a_{11}^2 \varepsilon_{1,t-1}^2 + b_{11}^2 h_{11,t-1}
\]

\[
h_{22,t} = c_{21}^2 + c_{22}^2 + a_{22}^2 \varepsilon_{2,t-1}^2 + b_{22}^2 h_{22,t-1}
\]

\[
h_{12,t} = h_{21,t} = c_{11} c_{22} + b_1 b_2 h_{12,t-1} + a_1 a_2 \varepsilon_{1,t-1} \varepsilon_{2,t-1}
\]

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.

\[
l(\theta) = -\frac{TN}{2} \log 2\pi - \frac{1}{2} \sum_{t=1}^{T} (\log |H_t| + \varepsilon_t' H_t^{-1} \varepsilon_t)
\]

where \( \theta \) 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 \( \theta \) is asymptotically normal, and thus traditional procedures for statistical inference are applicable (Heidari and Bashiri, 2011).

DATA

This paper uses the real exchange rate and the private investment in the Iranian economy covering the period of 1988 to 2007. All data are in logarithm form and are gathered from Central Bank of Iran (CBI) and International Financial Statistics (IFS) CD-ROM.

Figure 1 shows the logarithm of real exchange rate and private investment in the Iranian economy during 1988 to 2008. As Figure 1 shows the Iranian economy has experienced volatile real exchange rate and private investment during last two decades.

The summary statistics for the data is given in Table 1. The values of the Jargue-Bera statistic for the logarithm...
Figure 1. Logarithm of real exchange rate and private investment in the Iranian economy.

Table 1. Summary statistics for the logarithm of real exchange rate and private investment.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Std. Dev.</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Jarque-Bera</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>LRER</td>
<td>8.453</td>
<td>8.5075</td>
<td>8.8847</td>
<td>7.8156</td>
<td>0.2380</td>
<td>-0.7003</td>
<td>3.0566</td>
<td>6.7151</td>
<td>0.03482</td>
</tr>
<tr>
<td>LPRI</td>
<td>9.591</td>
<td>9.5735</td>
<td>10.3689</td>
<td>8.8520</td>
<td>0.4521</td>
<td>0.0692</td>
<td>1.7964</td>
<td>4.8926</td>
<td>0.08661</td>
</tr>
</tbody>
</table>

The results of these standard unit root tests in Table 2 are not the same. These results, however, are biased in favor of identifying data as integrated in the presence of structural break. So, we use structural break tests and unit root with structural break tests.

To carry out a test of no structural break against an unknown number of breaks in the variables under investigation, we use the endogenously determined multiple break tests introduced by Bai and Perron (1998, 2003). The results show that using most of these tests, we have breaks in the mean of the series under considerations.

To carry out a unit root test with presence of any structural break, we use Lee and Strazicich (2004) test which introduced a new procedure to capture two structural breaks. Table 3 presents the results of Lee and Strazicich (2004) unit root test.

The results reveals in Table 3 that in the presence of two structural breaks, the null of unit root for logarithm of real exchange rate and private investment are rejected at 1% level of significance.

Empirical results

We use a VAR(1)-GARCH-M model to estimate the relationships between real exchange rate and private investment and their respective uncertainties simultaneously. The method for the estimation of parameters which we use is maximum log-likelihood with BEKK approach. The estimated bivariate BEKK model is reported in Table 4.

\( \phi_2 \) which shows the mean spillovers from real exchange rate to private investment is negative and significant, which means that real exchange rate affects the level of private investment. \( \phi_3 \) which implies the mean spillovers from private investment to real exchange rate, is negative and significant. Thus, there are bidirectional mean spillovers between real exchange rate and private investment.

The coefficients of real exchange rate and private investment with one lag in their mean equations are positive and significant, which indicates that private investment is affected by its lag value and real exchange rate is positively affected by its lag value.

However, the coefficient of conditional variance of real exchange rate in the mean equation is negative and insignificant, which means that real exchange rate uncertainty does not affect the level of real exchange rate.

Moreover, our empirical evidence shows that real exchange rate uncertainty affects on the investment inversely, supporting, Dixit and Pindyck (1994). This is in line with Goldberg (1993), Serven and Solimano (1993), Bleaney (1996), Darby et al. (1999, 2000), Bleaney and Greenaway (2001), Bohm and Funke (2001) Serven (2002), Atella et al. (2003), Becker et al. (2003), Byrne et
Table 2. ADF, PP, KPSS and NP tests results for logarithm of real exchange rate and private investment.

<table>
<thead>
<tr>
<th>Statistics level</th>
<th>Real exchange rate statistics</th>
<th>Lag</th>
<th>Result</th>
<th>Private investment statistics</th>
<th>Lag</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{\mu}$ (ADF)</td>
<td>-0.8797</td>
<td>0</td>
<td>I(1)</td>
<td>-0.3666</td>
<td>9</td>
<td>I(1)</td>
</tr>
<tr>
<td>$\tau_T$ (ADF)</td>
<td>-1.9650</td>
<td>0</td>
<td>I(1)</td>
<td>-2.2490</td>
<td>9</td>
<td>I(1)</td>
</tr>
<tr>
<td>$\tau$ (ADF)</td>
<td>-1.5094</td>
<td>0</td>
<td>I(1)</td>
<td>1.1489</td>
<td>9</td>
<td>I(1)</td>
</tr>
<tr>
<td>$\tau_{\mu}$ (PP)</td>
<td>-0.6518</td>
<td>2</td>
<td>I(1)</td>
<td>-0.7828</td>
<td>5</td>
<td>I(1)</td>
</tr>
<tr>
<td>$\tau_T$ (PP)</td>
<td>-1.8915</td>
<td>1</td>
<td>I(1)</td>
<td>-1.9388</td>
<td>5</td>
<td>I(1)</td>
</tr>
<tr>
<td>$\tau$ (PP)</td>
<td>-1.7459</td>
<td>4</td>
<td>I(1)</td>
<td>1.4471</td>
<td>5</td>
<td>I(1)</td>
</tr>
<tr>
<td>$\tau_{\mu}$ (kpss)</td>
<td>0.8936</td>
<td>6</td>
<td>I(0)</td>
<td>0.9948</td>
<td>6</td>
<td>I(1)</td>
</tr>
<tr>
<td>$\tau_T$ (kpss)</td>
<td>0.2301</td>
<td>6</td>
<td>I(0)</td>
<td>0.1611</td>
<td>6</td>
<td>I(1)</td>
</tr>
<tr>
<td>MZ$\mu$(np)</td>
<td>1.0790</td>
<td>0</td>
<td>I(1)</td>
<td>0.4088</td>
<td>9</td>
<td>I(1)</td>
</tr>
<tr>
<td>MZ$\mu$(np)</td>
<td>0.4597</td>
<td>0</td>
<td>I(1)</td>
<td>0.2248</td>
<td>9</td>
<td>I(1)</td>
</tr>
<tr>
<td>MZ$\tau$(np)</td>
<td>-8.5271</td>
<td>2</td>
<td>I(1)</td>
<td>-61.861</td>
<td>9</td>
<td>I(0)</td>
</tr>
<tr>
<td>MZ$\tau$(np)</td>
<td>-1.9420</td>
<td>2</td>
<td>I(1)</td>
<td>-5.5568</td>
<td>9</td>
<td>I(0)</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Variable</th>
<th>TB1</th>
<th>TB2</th>
<th>K</th>
<th>t-statistic</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>LRER</td>
<td>1995Q1</td>
<td>1998Q4</td>
<td>6</td>
<td>-6.5877</td>
<td>I(0)</td>
</tr>
<tr>
<td>LRPI</td>
<td>1993Q4</td>
<td>1996Q3</td>
<td>8</td>
<td>-8.4155</td>
<td>I(0)</td>
</tr>
</tbody>
</table>

$\tau_T$ represents the most general model with a drift and trend; $\tau_{\mu}$ is the model with a drift and without trend; $\tau$ is the most restricted model without a drift and trend. The critical values are obtained from Mackinnon (1991) for the ADF and PP test and from Kwiatkowski et al. (1992) for the KPSS test and from Ng-Perron(2001) for the NP test. Tests for unit roots have been carried out in EVIEW 6.0.

Our results suggest that the real exchange rate uncertainty seems to become an impediment to the private investment. Therefore, the negative effect of real exchange rate uncertainty on the private investment is higher than real exchange rate, because in Iranian economy real exchange rate uncertainty, because of instability of polices, reduces the price mechanism's efficiency to optimize the allocation of resources, distorts the real cost of purchasing imported capital goods, intermediate goods and inputs, therefore, the profitability of the private sector is affected and this may reduce private investment. Our empirical evidence also shows that private effect on the private investment. This result means investment uncertainty has a negative and significant level of that private investment equation, the coefficient $a_{11}$ is significant at the 1% level, indicating the
Table 4. Estimated parameters of Bivariate BEKK model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. error</th>
<th>z-Statistic</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_1$</td>
<td>1.540657</td>
<td>0.460983</td>
<td>3.342112</td>
<td>0.0008</td>
</tr>
<tr>
<td>$\phi_1$</td>
<td>0.907428</td>
<td>0.022105</td>
<td>41.05068</td>
<td>0.0000</td>
</tr>
<tr>
<td>$\phi_2$</td>
<td>-0.070394</td>
<td>0.030049</td>
<td>-2.342595</td>
<td>0.0192</td>
</tr>
<tr>
<td>$\rho_1$</td>
<td>-14.06188</td>
<td>3.986633</td>
<td>-3.527256</td>
<td>0.0004</td>
</tr>
<tr>
<td>$\rho_2$</td>
<td>-1.030794</td>
<td>0.499902</td>
<td>-2.061990</td>
<td>0.0392</td>
</tr>
<tr>
<td>$\mu_2$</td>
<td>2.169492</td>
<td>0.606297</td>
<td>3.578265</td>
<td>0.0003</td>
</tr>
<tr>
<td>$\phi_3$</td>
<td>-0.103649</td>
<td>0.025714</td>
<td>-4.030792</td>
<td>0.0001</td>
</tr>
<tr>
<td>$\phi_4$</td>
<td>0.861436</td>
<td>0.046534</td>
<td>18.51190</td>
<td>0.0000</td>
</tr>
<tr>
<td>$\rho_3$</td>
<td>-0.721830</td>
<td>1.678124</td>
<td>-0.430141</td>
<td>0.6671</td>
</tr>
<tr>
<td>$\rho_4$</td>
<td>-1.490640</td>
<td>2.323146</td>
<td>-0.641647</td>
<td>0.5211</td>
</tr>
<tr>
<td>$c_{11}$</td>
<td>0.005104</td>
<td>0.001023</td>
<td>4.988111</td>
<td>0.0000</td>
</tr>
<tr>
<td>$b_{11}$</td>
<td>0.899495</td>
<td>0.018051</td>
<td>49.82965</td>
<td>0.0000</td>
</tr>
<tr>
<td>$a_{11}$</td>
<td>0.140501</td>
<td>0.165160</td>
<td>0.850694</td>
<td>0.3949</td>
</tr>
<tr>
<td>$c_{22}$</td>
<td>0.014193</td>
<td>0.008399</td>
<td>1.689841</td>
<td>0.0911</td>
</tr>
<tr>
<td>$c_{21}$</td>
<td>-0.009895</td>
<td>0.009962</td>
<td>-0.993290</td>
<td>0.3206</td>
</tr>
<tr>
<td>$b_{22}$</td>
<td>0.614380</td>
<td>0.171640</td>
<td>3.579457</td>
<td>0.0003</td>
</tr>
<tr>
<td>$a_{22}$</td>
<td>0.762813</td>
<td>0.174711</td>
<td>4.366141</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

the private investment has time varying variance characteristic. In real exchange rate equation, the coefficients $a_{22}$ and $b_{22}$ are statistically significant at the 1% level, indicating there exist ARCH and GARCH effects.

Equation 1 shows that these models allow for dynamic dependence between the volatility of the series under consideration. Figures 2 and 3 show the conditional covariance and variance of real exchange rate and private investment. It can be seen from the behavior of conditional covariance (Figure 2) that correlation between real exchange rate uncertainty and private investment uncertainty is stable over time.

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

**Conclusion**

Real exchange rate uncertainty, as the most important index to macroeconomic instability, plays an important role in investment decisions. It reduces the price mechanism's efficiency to optimize the allocation of resources, distorts the real cost of purchasing imported capital goods, intermediate goods and inputs, therefore the profitability of the private sector is affected and this may reduce private investment.

In addition, exchange rate uncertainty may lead to change in real income, and this could modify the production capacity. Also, it affects sectors which produce international traded goods, and thus influence the competitive and export volume.

So, in this paper, we have investigated empirically the relationship between real exchange rate and private investment and their respective uncertainties in Iran for the period of 1988 to 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) There are bidirectional mean spillovers between real exchange rate and private investment. (2) Real exchange rate uncertainty significantly influences
private investment and has a negative effect on it, supporting Dixit and Pindyck (1994). (3) Private investment uncertainty affects the level of private investment, negatively. Therefore, in order to increase the private investment, government should create a stable macroeconomic environment.

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