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The Contribution of Observed and Unobserved Fundamentals to Exchange Rate Movements in Iran

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Abstract

Using a State-space model, this paper investigates the contribution of both observed and unobserved fundamentals to nominal exchange rate movement in Iran for the period 1991:2-2011:4. To this end, we follow Engel and West (2005) and Balke et al. (2013) and use an asset-pricing approach to develop a rational expectations present value exchange rate model. In order to examine the role of fundamental factors in exchange rate determination, we estimate the variance contribution of each factor to variance decomposition of the deviation of exchange rate from its long run equilibrium. The random walk Metropolis-Hastings algorithm, Kalman filter and Carter and Kohn algorithm are used to decompose the variance contributions. The results show that the observable fundamentals and the unobserved monetary

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demand shocks explain about 58.9 and 38.7 percentages of exchange rate fluctuation, respectively. Hence, contrary to previous studies in Iran, which have focused mainly on observable fundamental factors, we find that the unobservable fundamentals also play key role in determining the exchange rate movement in this country. Moreover, we find that the nominal exchange rate does not follow a near random walk behavior. It implies that the foreign exchange rate market in Iran is not efficient. Our findings might have important policy implications for monetary authorities.

Keywords: *Nominal exchange rate, Observable fundamental factor, Unobservable fundamental factors, State-space model, Bayesian analysis.*

JEL Classification*: F31, C32, C12*

1. Introduction

Since the collapse of currency reserve system in the early 1970s, numerous theoretical and empirical works have focused on key determinants of exchange rate fluctuations. Early studies have put emphasize on the contribution of observed fundamental factors to exchange rate movement. However, more recently, some authors have distinguished between fundamental and non-fundamental factors in explaining the exchange rate. The fundamentals can also be divided into observable and unobservable factors.

Some empirical researches find fragile relationship between the nominal exchange rate and fundamentals and hence have questioned the use of structural models to estimate exchange rate. For example, Meese and Rogoff (1983) demonstrated that a random walk model out performs structural models in term of out of sample prediction in explaining exchange rate behavior. In contrast, some subsequent studies rejected the use of random walk model for forecasting exchange rate movement.[1] However, as we will discuss later, more recently some authors have used sophisticated econometric techniques and found evidence in favor of long-run equilibrium relationship between nominal exchange rates and fundamentals. These authors have tried to resolve the so called "the disconnect puzzle" between nominal exchange rate and fundamentals. For example, Engel and West (2005) have developed a rational expectation model and demonstrated that the present discounted value of expected economic fundamentals can describe the fluctuation of spot exchange rate around its long-run equilibrium. They make use of an asset-pricing approach in which the exchange rate is the expected present discounted value of a linear combination of observable and unobservable fundamentals. They prove that

1. See Cheung et al. (2005) and Sarno (2005).

if the fundamentals are integrated of order one and the discounting factor is close to one, an asset price displays near random walk behavior.

As a result, part of the literature attempts to explain the deviation of nominal exchange rate from its observed fundamentals by introducing unobserved factors into a rational expectation model. Thus, ignoring the importance of unobservable factors in modeling and estimating exchange rate might leave a large part of nominal exchange rate fluctuation unexplained.

In short, many studies such as Mark and Sul (2001), Wohar and Rapach (2002), Cerra and Saxena (2010), and Kim et al. (2010) have used monetary variables such as money supply differentials, and output differentials to examine the contribution of observable fundamentals to nominal exchange rate fluctuations. However, the empirical results have shown that the unobserved fundamental factors might also improve our forecast of future nominal exchange rates. For example, Balke et al. (2013) have shown that money demand shifter as an unobservable fundamental also plays a key role in explaining the behavior of nominal exchange rate.

Most studies in Iran have employed the monetary approach to examine the nominal exchange rate movements.[1] The results have shown that observable fundamental variables such as money supply, real interest rate and real GDP differentials are key determinants of nominal exchange rate in this country. However, as far as we know, none of these studies have examined the contribution of unobservable fundamental factors to nominal exchange rate fluctuations. In other words, the literature on nominal exchange rate movement in Iran has not explicitly modeled the role of unobserved factors in explaining exchange rate movement. This study aims to fill this gap in the empirical literature for the case of Iran. More specifically, we follow the model developed by Engel and West (2005) and Balke et al. (2013) to estimate the deviation of the nominal exchange rate

1. See Section 2.

from its long-run equilibrium by introducing both observable and unobservable fundamental factors to a monetary model for Iran.

Given the presence of unobserved variables in our model, we use a State-space model to investigate the contribution of both observable and unobservable fundamental factors to the deviation of nominal exchange rate from its long run equilibrium. In particular, we employ the Bayesian analysis to estimate our State-space model. Since in our case, the log-likelihood of the State-space model is a nonlinear function of the structural parameters, we use the Bayesian Markov Chain Monte Carlo methods to estimate the posterior distributions of fundamental factors.

More specifically, we will use Kalman filter, and Metropolis-Hastings algorithm to investigate the contribution of both unobserved and observed fundamentals to spot exchange rate movement in the context of a monetary model in Iran. The results can provide a better understanding of the factors determining exchange rate fluctuation in Iran and, hence, might have important policy implications for the policymakers.

The rest of the paper is organized as follows: Section 2 surveys the literature. In this section some empirical studies on nominal exchange rate movements will be reviewed. Section 3 presents the State-space modeling of nominal exchange rate movement. In this section the deviation of spot exchange rate from its fundamental is written as a function of expectations of future observable and unobservable fundamentals. The estimation results are reported in section 4. Section 5 concludes.

2. Literature Review

Some empirical researches and evidences cast doubt on the importance of fundamental factors in predicting exchange rate movement. They show that fundamental factors might not be able to explain a large part of exchange rate behavior (Haushofer et al., 2005, 59). Hence, they underline the role of non-fundamental factors in explaining a substantial part of exchange rate movements. This has induced some researchers to differentiate between fundamental and non-fundamental determinants of exchange rate (Vygodina et al., 2008, p.728). For example, Meese and Rogoff (1983) show that the performance of a Simple Random Walk model in forecasting exchange rate movement is better than that of structural models. The random walk behavior of exchange rate is related to the efficient market hypothesis (EMH). Under this hypothesis, only unanticipated shocks can affect the price of an asset (Mbululu et al., 2013, 48).

Following Meese and Rogoff (1983), other researchers such as Cheung et al. (2005), and Manzan and Westerhoff, (2007) also find weak relationship between the nominal exchange rate and fundamentals.

These findings have caused a debate among economists about the predictive power of structural models and random walk model in the literature of exchange rate determination. One possible explanation for the failure of the structural models in predicting future exchange rates is that the fundamental variables might play a less important role in explaining exchange rate behavior.[1]

Other researchers such as Manzan and Westrhoff (2007) argue that the structural models are successful in predicting the long-term behavior of the exchange rate, but they fail to explain the short-term dynamics of the exchange rate. Hence, they conclude that an appropriate model of exchange rate should incorporate both fundamental and non-fundamental factors.

The fundamental approach uses a variety of economic variables such as output growth, inflation rates, productivity, interest rate, money supply, trade balance, and unemployment to determine exchange rate.[2] According to

1. For more explanation on the collapse of fundamental models, we refer the readers to Frankel and Froot (1987), Lui and Mole (1998), Cheung and Chinn (2001) and Manzan and Westerhoff (2007), among others.
2. As will be seen later, the fundamental factors can be divided to observable and unobservable variables.

Haushofer et al. (2005), two approaches are identified in the theoretical literature on non-fundamental exchange rate determination: (1) the microstructure approach and (2) the dynamic equilibrium approach with heterogeneous foreign exchange market participants.[1] The non-fundamental factors might include speculative bubbles, overreaction of traders to news, and trading based on technical analysis (Manzan and Westerhoff, 2007, p. 112). These factors usually affect the exchange rate in the short run.

Despite the above argument, many researchers have focused on the role of fundamental variables in nominal exchange rate movement. Most of them have used monetary approach to exchange rate determination. For example, Ma and Kanas (2000) use a nonparametric nonlinear co-integration approach and also a nonlinear Granger causality approach to investigate a nonlinear relationship between macroeconomic fundamentals and nominal exchange rates for two country-pairs, namely the Netherlands-Germany and France-Germany. They show that there is a long-run nonlinear relationship among money, output and exchange rate for Netherlands-Germany. However, they find no co-integration among these variables for France-Germany. These authors show that these nonlinearities were not due to the presence of bubbles.

Mark and Sul (2001) study the relationship between nominal exchange rates and monetary fundamentals in a panel of 19 developed countries. They confirm the presence of long-run relationship between exchange rates and the fundamentals. They find that monetary fundamentals help to forecast future exchange rate returns in the countries under investigation. Cerra and Saxena (2010) find strong evidence for long-run relationship between nominal exchange rates and monetary fundamentals in 98 developed and developing countries. They also show that the fundamentals-based models are very successful in beating a random walk in out-of-sample prediction.

1. See Haushofer et al. (2005, p.72) for more details. The detailed explanation of these approaches is out of the scope of this paper and hence will not be pursued further here.

Kim et al. (2010) examines the nonlinear dynamics of exchange rate deviation from the monetary fundamentals for four countries, namely the Germany, United Kingdom, Japan and Switzerland. The results show that deviation of exchange rate from its monetary fundamentals follows a nonlinear model. They also find that predictability of the monetary model with nonlinear adjustment increases when the forecast horizon increases.

Junttila and Korhonen (2011) investigate the relationship between nominal exchange rate and macroeconomic fundamentals for five countries, namely the Germany, United Kingdom, Canada, France and Italy, for the post Bretton Woods period. They confirm the presence of nonlinear relationship between nominal exchange rate and the fundamentals.

Balke et al. (2013) develops a State-space model to examine the effect of observable and unobservable fundamental factors on nominal exchange rate movements in the UK for the period 1880-2010. The results show that both unobserved and observed fundamentals contribute to exchange rate movements.

Now, let us have a short review on the literature on nominal exchange rate movement in Iran. Most empirical works on exchange rate in this country have focused on real exchange rate fluctuation. However, there are some researchers that have studied the movement of nominal exchange rate. For example, Using Engel-Granger causality test and ordinary least square regression, Akhbari (2006) show that the growth of domestic money supply, GDP and interest rates differentials are the key determinants of nominal exchange rate movement in Iran.

Mohammadzadeh et al. (2008) also use the monetary approach to investigate nominal exchange rate movement in MENA countries in the context of panel data model for the period 1974-2004. The results show that monetary variables such as inflation rates, interest rates and GDP differentials affect the movement of nominal exchange rates in this region.

Using a vector error correction model, Kazerooni et al. (2010) shows that the inflation rates differentials and the money supply growth have positive effect and the real GDP differentials has negative effect on the nominal exchange rate in Iran. In contrast to this finding, Taghavi and Mohammadi (2011) estimate a simultaneous equations system and show that the monetary approach does not provide a strong support for black market exchange rate movement in Iran.

Asgharpur et al. (2011) employ a flexible price monetary model in the context of a Markov switching model to examine nominal exchange rate movement in Iran for the period 1978-2007. The results show that GDP differentials are the most important variables in explaining nominal exchange rate fluctuations. In addition, the growth of money supply and the inflation rate differentials also contribute to nominal exchange rate fluctuation in Iran.

Using a structural Vector Autoregressive model, Hemmati and Mobasherpour (2011) show that nominal shocks such as money supply might explain about 53 and 39 percentage of nominal exchange rate fluctuations in the short-run and long-run, respectively.

To sum up, we observe that the empirical studies in Iran have mainly focused on the role of observed fundamental factors in explaining nominal exchange rate movement. The majority of these researchers have modeled nominal exchange rate in the context of monetary approach. However, none of them has examined the contribution of unobservable fundamentals to nominal exchange rate fluctuations in this country. This paper will demonstrate the importance of unobserved factors for modeling exchange rate for Iran.

3. The Model

In order to examine the importance of both observable and unobservable fundamental factors in nominal exchange rate movement in Iran, we follow the works of Engel and West (2005) and Balke et al. (2013), and use an asset-pricing approach to develop a rational expectations present value exchange rate model. Exchange rate models after the collapse of Bretton Woods system in the early 1970s, have considered the nominal exchange rates as asset prices that are determined by expectations about the future. Consider the following asset pricing model in which the log of nominal spot exchange rate, s_t is equal to a discounted sum of current and expected future fundamentals. [1]

$$s_t = E_t \sum_{j=0}^{\infty} \psi^j (a' x_{t+j}),\ 0 < \psi < 1, \tag{1}$$

where x_t is the $(n \times 1)$ vector of fundamentals, and the symbol E_t indicates the mathematical expectations. It shows that expectations are formed based on all information available by the end of period t. The parameter ψ is a discount factor and a is $(n \times 1)$ vectors. The vector x_t includes both the observable and unobservable fundamentals. More specifically, we can express the model in the following form:

$$s_t = f_t + E_t \sum_{j=1}^{\infty} \psi^j (\Delta f_{t+j}) + R_t,\ 0 < \psi < 1, \tag{2}$$

in which s_t is defined as before, f_t is the current value of observed fundamentals. The final term R_t includes both current and expected future values of unobserved fundamentals and non-fundamental factors. [2]

Prior to estimate, the contribution of economic fundamentals to exchange rate movement in Iran, we have to express our model in terms of observable and unobservable fundamentals. More specifically, we will use the monetary

1. -See Engle and West (2005, p.489).
2. As Balke et al. (2013) pointed out observable fundamentals might include money growth and output growth differentials and unobservable fundamentals and non-fundamentals are risk premia, money demand shocks among others.

approach to exchange rate determination to drive our exchange rate model. Since we have both observable and unobservable variables, we closely follow Engel and West (2005) and Balke et al. (2013) and will express the above present value model in the form of a State-space model. Consider the following monetary model expressed by equation (3).

$$m_t - p_t = \emptyset y_t - \lambda i_t + v_t^{md} \quad , \qquad \emptyset > 0,\ \lambda > 0 \tag{3a}$$

$$m_t^* - p_t^* = \emptyset y_t^* - \lambda i_t^* + v_t^{*md} \ . \tag{3b}$$

The variables in the above equations are money supply (m), price level (p), real GDP (y) and nominal interest rate (i). All variables are in natural logarithm except the interest rates. The asterisk denotes foreign variable. The term v_t^{md} and v_t^{*md} stand for unobservable variables that affect the demand for money in domestic and foreign countries, respectively. The parameters $\emptyset$ and λ represent income elasticity and interest semi-elasticity of money demand, respectively.

The above model will be combined with the uncovered interest parity (UIP) condition. Following Balke et al. (2013), we introduce a time-varying risk premium r_t^{uip} into UIP condition. The UIP condition is written below.

$$i_t - i_t^* = E_t s_{t+1} - s_t + r_t^{uip} \tag{4}$$

The variables are defined as before.[1] $E_t s_{t+1}$ denotes the expected log of spot exchange rate in time t+1. In order to complete the model, we follow the literature and introduce the following purchasing power parity relationship:

$$s_t = p_t - p_t^* + r_t^{ppp} \tag{5}$$

1. We treat Iran as the home country and the US as the foreign country. The exchange rate is quoted as Rial per Dollar.

The deviation from purchasing power parity is captured by the variable r_t^{ppp}. By substituting p_t and p_t^* from equations (3a) and (3b) into equation (5) we obtain equation (6).

$$s_t = (m_t - m_t^*) - \emptyset(y_t - y_t^*) + \lambda(i_t - i_t^*) - (v_t^{md} - v_t^{*md}) + r_t^{ppp} \quad (6)$$

After substituting $i_t - i_t^*$ from equation (4) into equation (6) we get:

$$s_t = f_t + \lambda\left(E_t s_{t+1} - s_t + r_t^{uip}\right) - (v_t^{md} - v_t^{*md}) + r_t^{ppp} \quad (7)$$

in which the observable monetary fundamental is denoted by $f_t \equiv (m_t - m_t^*) - \emptyset(y_t - y_t^*)$ and the unobservable variables are v_t^{md} , v_t^{*md}, r_t^{uip} and r_t^{ppp} . We follow Rapach and Wohar (2002) and Balke et al. (2013) and set $\emptyset = 1$. In many studies such as Mark and Sul (2001), Sarno (2009) and Kim et al. (2010), f_t is considered to be the main determinants of the long-run equilibrium exchange rate. As Mark and Sul (2001, p.32) points out "the common feature shared by the various theories is that the long-run equilibrium exchange rate is governed by determinants of money market equilibrium at home and abroad." Therefore, the variation of nominal exchange rate from its observable fundamentals, i.e., $s_t - f_t$ can be written as:

$$s_t = f_t + \lambda\left(E_t s_{t+1} - s_t + r_t^{uip}\right) - (v_t^{md} - v_t^{*md}) + r_t^{ppp} \quad (8)$$

$$s_t - f_t = \Psi E_t[s_{t+1} - f_{t+1}] + \Psi E_t[\Delta f_{t+1}] + R_t \ , \quad (9)$$

By adding and subtracting the terms λf_t and $\lambda E_t f_{t+1}$ to the right-hand side of equation (8) and then multiplying by the term $\frac{1}{1+\lambda}$, we get:
in which $\Psi = \frac{\lambda}{1+\lambda}$ denotes the discount factor. The term R_t, in equation (9) contains the unobservable variables that shift money demand (i.e., $r_t^{md} = v_t^{md} - v_t^{*md}$), and the variables that capture the deviations from uncovered

interest rate parity and purchasing power parity (i.e., ${r_t}^{uip}$ and ${r_t}^{ppp}$). In other words, R_t is equal to $(\Psi {r_t}^{uip} + (1-\Psi){r_t}^{ppp} - (1-\Psi){r_t}^{md})$.

Provided a stable solution exists, we can solve the above expectational difference equation and obtain:[1]

$$s_t - f_t = E_t\left[\sum_{j=1}^{\infty} \Psi^j \Delta f_{t+j}\right] + E_t\left[\sum_{j=0}^{\infty} \Psi^j R_{t+j}\right] \qquad (10)$$

This equation shows that the expected present discounted value of future observable and unobservable fundamentals determine the deviation of spot exchange rate from its long-run equilibrium.

However, the expectations of future fundamentals are not observable. In order to be able to estimate the contribution of unobserved fundamental factors, we follow Balke et al. (2013) and write equation (10) in the form of a State-space model. In this framework, the expectations are treated as latent factors.

Let us define $r_{t+j} = \frac{R_{t+j}}{\Psi}$. Hence, as equation (10) shows, the deviation of nominal exchange rate from its long-run equilibrium depends on expectations of Δf_{t+j} and expectations of r_{t+j}. We follow Balke et al. (2102) and denote $E_t[\Delta f_{t+1}]$ by g_t and $E_t[r_{t+1}]$ by μ_t.

The variables Δf_t and r_t are equal to the sum of their conditional expectation and a forecast error realized at time t as defined below:

$$\Delta f_t = g_{t-1} + \varepsilon_t^f \qquad (11)$$

$$r_t = \mu_{t-1} + \varepsilon_t^r \qquad (12)$$

The un-forecastable shocks ε_t^f and ε_t^r are assumed to be white noise. The predictable components of equations (11) and (12), namely g_{t-1} and μ_{t-1} are assumed to follow autoregressive processes defined below:

$$g_t = \emptyset_g(L) g_{t-1} + \varepsilon_t^g \qquad (13)$$

1. Equation (10) is derived by Balke et al. (2013).

$$\mu_t = \emptyset_\mu(L)\mu_{t-1} + \varepsilon_t^\mu, \tag{14}$$

where ε_t^g and ε_t^μ are news (shocks) and L is lag operator. The dynamics of the predictable components are explained by the lag polynomials $\emptyset_g(\mathrm{L}) = \sum_{i=1}^{k} \emptyset_{g,i}\mathrm{L}^{i-1}$ and $\emptyset_\mu(L) = \sum_{i=1}^{k} \emptyset_{\mu,i}L^{i-1}$. The shocks ($\varepsilon_t^g$, ε_t^μ, ε_t^f, ε_t^r) are assumed to be contemporaneously correlated. However, they are serially uncorrelated. It implies that Δf_t and r_t follow autoregressive moving average processes [ARMA (k, max (1,k))][1]. Using the above discussion, equation (10) can be written as:

$$s_t - f_t = B_1(L)g_t + B_2(L)\mu_t + \Psi\mu_{t-1} + \Psi{\varepsilon_t}^r \tag{15}$$

where $B_1(L)g_t = E_t\left[\sum_{j=1}^{\infty}\Psi^j\Delta f_{t+j}\right]$, $B_2(L)\mu_t = E_t\left[\sum_{j=1}^{\infty}\Psi^{j+1}r_{t+j}\right]$ and $\Psi\mu_{t-1} + \Psi{\varepsilon_t}^r = \Psi r_t$. It shows that the value of Ψ, $\emptyset_g(L)$ and $\emptyset_\mu(L)$ affect the coefficients of the lag polynomials, $B_1(L)$ *and* $B_2(L)$. According to equation (15), the deviation of nominal exchange rate from its long-run equilibrium depends on the expectations of observed and unobserved variables.

Given the presence of unobserved variables in our dynamic system, we write equations (11), (13), (14), and (15) in the form of a State-space model. A State-space model is made of a measurement equation and a transition equation. The relation between the observed variables and the unobserved State variables is expressed by a measurement equation. A transition equation describes the dynamics of the state variables.[2] We can use equations (11) and (15) and write the measurement equation of our State-space model in the following form:

$$\begin{bmatrix}\Delta f_t \\ s_t - f_t\end{bmatrix} = \begin{bmatrix} L & 0 & 1 & 0 \\ B_1(L) & (B_2(L)+\Psi) & 0 & \Psi\end{bmatrix}\begin{bmatrix} g_t \\ \mu_t \\ \varepsilon_t^f \\ {\varepsilon_t}^r\end{bmatrix} \tag{16}$$

1. The term k denotes the number of autoregressive terms in $\emptyset_g(L)$ and $\emptyset_\mu$.

2. See Kim and Nelson (1999, p.29).

The dynamics of our State variables can be described by the following transition equation:

$$\begin{bmatrix} g_t \\ \mu_t \\ \varepsilon_t^f \\ \varepsilon_t{}^r \end{bmatrix} = \begin{bmatrix} \emptyset_g(L) & 0 & 0 & 0 \\ 0 & \emptyset_\mu(L) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} g_{t-1} \\ \mu_{t-1} \\ \varepsilon_{t-1}^f \\ \varepsilon_{t-1}^r \end{bmatrix} + \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^\mu \\ \varepsilon_t^f \\ \varepsilon_t^r \end{bmatrix} \tag{17}$$

One important issue about State-space models is identification[1]. Balke et al. (2013, p.4) showed that if the ratio of $\sigma^2{}_g/\sigma^2{}_f$ is relatively small, then observations of Δf_t are not sufficient to identify $\phi_g(L)$. Balke et al. (2013) in the empirical part of their paper confirmed that this ratio is small. This implies that the data on s_t-f_t may not be sufficient to identify g_t and μ_t separately. In other words, since a single data series is used to identify two components (i.e., g_t and μ_t), the model is weakly identified. In this case, the State-space model represented by equations (16) and (17) has identification problem. In order to resolve this problem, it is suggested to include additional observations which are related to the unobserved state variables into the model. In this paper, we use observations on price differentials $(p_t - p_t^*)$ and interest rate differentials $(i_t - i_t^*)$ as the additional data to be included in the model.[2]

The monetary model developed earlier suggests that the components of R_t (i.e., r_t^{md}, r_t^{uip} and r_t^{ppp}) and the observable fundamentals affect the dynamics of nominal exchange rate. Moreover, we know that price differentials and interest rate differentials are related to R_t. Suppose that these components have both predictable and unpredictable parts. Hence, the four components of exchange rates are assumed to have the following forms:

$$\Delta f_t = g_{t-1} + \varepsilon_t^f, \quad g_t = \emptyset_g(L) g_{t-1} + \varepsilon_t^g , \tag{18}$$

1. For more details, see Hamilton Time Series Analysis, chapter 13.
2. According to the monetary model of exchange rate, these observations are related to the unobservable variables r_t^{md}, r_t^{uip} *and* r_t^{ppp}. Balke et al. (2013) also included these observations in their work.

$$r_t^{ppp} = \mu_{t-1}^{ppp} + \varepsilon_t^{ppp},\ \mu_t^{ppp} = \emptyset_{ppp}(\mathrm{L})\mu_{t-1}^{ppp} + \varepsilon_T^{\mu,PPP}, \tag{19}$$

$$r_t^{uip} = \mu_{t-1}^{uip} + \varepsilon_t^{uip},\quad \mu_t^{uip} = \emptyset_{uip}(\mathrm{L})\mu_{t-1}^{uip} + \varepsilon_t^{\mu,uip}, \tag{20}$$

$$r_t^{md} = \mu_{t-1}^{md} + \varepsilon_t^{md},\ \mu_t^{md} = \emptyset_{md}(L)\mu_{t-1}^{md} + \varepsilon_t^{\mu,md}, \tag{21}$$

where the terms ε_t^f, ε_t^{ppp}, ε_t^{uip} and ε_t^{md} are unpredictable components and g_t, μ_t^{ppp}, μ_t^{uip} and μ_t^{md} are predictable components. For simplicity, we assume the predictable components follow a AR(1) process. Then, the state vector of the State-space model can be written as:

$$S_t = \left[g_t\ g_{t-1}\ \mu_t^{uip}\mu_{t-1}^{uip}\ \mu_t^{ppp}\mu_{t-1}^{ppp}\mu_t^{md}\ \mu_{t-1}^{md}\quad \varepsilon_t^f\varepsilon_t^{uip}\quad \varepsilon_t^{ppp}\varepsilon_t^{md}\right]' \tag{22}$$

The transition equation is given by.

$$S_t = \mathrm{F}S_{t-1} + V_t\ , \tag{23}$$

with

$$V_t = \left[\varepsilon_t^g\quad 0\quad \varepsilon_t^{\mu,uip}\quad 0\quad \varepsilon_t^{\mu,ppp}\quad 0\quad \varepsilon_t^{\mu,md}\quad 0\quad \varepsilon_t^f\varepsilon_t^{uip}\varepsilon_t^{ppp}\varepsilon_t^{md}\right]'$$

and

$$F = \begin{bmatrix} \phi_g & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \phi_{uip} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \phi_{ppp} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \phi_{md} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Hence, the transition equation can be rewritten as:

$$\begin{bmatrix} g_t \\ g_{t-1} \\ \mu_t^{uip} \\ \mu_{t-1}^{uip} \\ \mu_t^{ppp} \\ \mu_{t-1}^{ppp} \\ \mu_t^{md} \\ \mu_{t-1}^{md} \\ \varepsilon_t^{f} \\ \varepsilon_t^{uip} \\ \varepsilon_t^{ppp} \\ \varepsilon_t^{md} \end{bmatrix} = \begin{bmatrix} \phi_g & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \phi_{uip} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \phi_{ppp} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \phi_{md} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} g_{t-1} \\ g_{t-2} \\ \mu_{t-1}^{uip} \\ \mu_{t-2}^{uip} \\ \mu_{t-1}^{ppp} \\ \mu_{t-2}^{ppp} \\ \mu_{t-1}^{md} \\ \mu_{t-2}^{md} \\ \varepsilon_{t-1}^{f} \\ \varepsilon_{t-1}^{uip} \\ \varepsilon_{t-1}^{ppp} \\ \varepsilon_{t-1}^{md} \end{bmatrix} + \begin{bmatrix} \varepsilon_t^{g} \\ 0 \\ \varepsilon_t^{\mu,uip} \\ 0 \\ \varepsilon_t^{\mu,ppp} \\ 0 \\ \varepsilon_t^{\mu,md} \\ 0 \\ \varepsilon_t^{f} \\ \varepsilon_t^{uip} \\ \varepsilon_t^{ppp} \\ \varepsilon_t^{md} \end{bmatrix}$$

As it was mentioned earlier, we follow Blake et al. (2013) and include data on interest rate[1] and price level differentials into our model. Hence, the observation vector contains the gap between observable fundamental and price level in the two countries $((m_t\text{-}\ y_t\text{-}\ p_t) - (m_t^*\text{-}\ y_t^*\text{-}\ p_t^*) = f_t\text{-}(p_t\text{-}\ p_t^*))$, the gap between interest rate in the two countries $(i_t - i_t^*)$, the observable fundamentals rate of growth (Δf_t), and the natural log of the spot exchange rate minus current observable fundamental $(s_t - f_t)$.

In the context of our monetary model, the equation for the gap between observed fundamental and price level differential can be written by:

$$f_t\text{-}\ (p_t\text{-}\ p_t^*) = -\frac{\Psi}{1-\Psi}(i_t - i_t^*) + r_t^{md}. \tag{24}$$

Using the uncovered interest rate parity condition, we can write:

1. The rate of interest is replaced with expected rate of profit for the case of Iran.

$$i_t - i_t^* = E_t(s_{t+1} - f_{t+1}) + E_t\Delta f_{t+1} - (s_t - f_t) + r_t^{uip}. \qquad (25)$$

One should bear in mind that the growth of observable fundamentals is given by:

$$\Delta f_t = g_{t-1} + \varepsilon_t^f \qquad (26)$$

and the deviation of nominal exchange rate from the fundamentals is given by:

$$s_t - f_t = E_t\left[\sum_{j=1}^{\infty} \Psi^j \Delta f_{t+j}\right] + E_t\left[\sum_{j=0}^{\infty} \Psi^{j+1} r_{t+j}\right], \qquad (27)$$

in which $\Psi r_t = \Psi r_t{}^{uip} + (1-\Psi) r_t{}^{ppp} - (1-\Psi) r_t{}^{md}$. Using equations (24)-(27), we can write the measurement equation:

$$\begin{bmatrix} f_t - (p_t - p_t^*) \\ i_t - i_t^* \\ \Delta f_t \\ s_t - f_t \end{bmatrix} = \begin{bmatrix} -\frac{\psi}{1-\psi}\left((H_{sf} + H_{\Delta f})F - H_{sf} + H_{uip}\right) + H_{md} \\ (H_{sf} + H_{\Delta f})F - H_{sf} + H_{uip} \\ H_{\Delta f} \\ H_{sf} \end{bmatrix} S_t, \qquad (28)$$

in which $H_{\Delta f} = [010000001000]$, $H_{uip}[000100000100]$

$H_{md} = [00000010001]$, $H_{sf} = [B_{11} \quad B_{12} \quad B_{21} \quad B_{22} \quad B_{31} \quad B_{32} \quad B_{41} \quad B_{42} \quad 0 \quad \psi \quad 1-\psi \quad -(1-\psi)]$,

$[B_{11} \quad B_{12}] = [\psi \cdot (1-\psi\phi_g)^{-1} \quad 0]$, $[B_{21} \quad B_{22}] = [\psi^2 \cdot (1-\psi\phi_{uip})^{-1} \quad \psi]$,

$[B_{31} \quad B_{32}] = \left[(1-\psi)\psi \cdot (1-\psi\varphi_{ppp})^{-1} \quad (1-\psi)\right]$,

$[B_{41} \quad B_{42}] = [-(1-\psi)\psi \cdot (1-\psi\phi_{md})^{-1} \quad -(1-\psi)]$.

B_{11}, B_{21}, B_{31} and B_{41} contain observable fundamentals, deviations from UIP, deviations from PPP and money demand shocks, respectively.

4. Data and Estimation

The quarterly data on nominal exchange rate (Rial per US Dollar), broad definition of money (M2), real gross domestic product (GDP), consumer price index (CPI) and interest rates[1] for Iran and the United states are obtained from the Central Bank of Iran and the Federal Reserve Bank of St. Louis. Our data set covers the period 1991:2 - 2011:4.

We follow Bayesian method[2] and use the random walk Metropolis-Hastings algorithm to estimate the unknown parameters in our State-space model. This algorithm allows us to derive variance decomposition of fundamental factors. In order to estimate variance decomposition of fundamentals, we need to have observations on these unobserved factors. [3] More specifically, we employ Carter and Kohn (1994) algorithm which allows us to use the Gibbs-sampling in the context of State-space models.[4] Using this algorithm, we simulate the observations on fundamentals.[5]

4.1. The estimation results of the State-space model

In this section we report the estimation results of our State-space model.[6] The random walk Metropolis-Hastings algorithm is used to estimate the unknown parameters associated with both the unobserved and observed fundamental variables. Using Gibbs sampling in the context of state space model,[7] we generated data on observed and unobserved fundamentals. We

1. We have used data on expected rate of profit on investment deposits to replace interest rate for the case of Iran.
2. Prior to apply the Metropolis-Hastings algorithm to our State-space model, we use Kalman filter to estimate a likelihood function. For more detail see Kim and Nelson (1999).
3. For more detail on Metropolis-Hastings algorithm, see Blake and Mumtaz (2012).
4. In order to use the Gibbs sampling algorithm one need to know the conditional distributions. However, the conditional distributions are not available in our case.
5. For details on how to use the random walk Metropolis Hastings algorithm for a state space model, we refer the readers to Blake and Mumtaz (2012), Chapter 4.
6. Matlab is used to estimate the model. The Matlab codes are not reported here but are available upon request.
7. In this specific case we use Carter and Kohn algorithm.

will present the posterior distributions of the variance decomposition of $(s_t - f_t)$ in Section (5.2).

As we mentioned earlier, $\emptyset_g$, $\emptyset_{uip}$, $\emptyset_{ppp}$ and $\emptyset_{md}$ are unknown parameters in our transition[1] equation. Since no information about these parameters is available for the case of Iran, we could not make use of any prior distribution for them. Hence, we use the random walk Metropolis-Hastings algorithm to generate posterior distributions for the unknown parameters of equation (23). This algorithm repeated 1000,000,000 times and we set a burn-up period of 500,000 draws, and then sampled the next 500,000 draws. Table (1) reports the mode of the posterior distribution of these parameters.

Table 1: The mode of posterior distributions of the parameters

Parameters	The mode of posterior distribution
$\emptyset_g$	0.81
$\emptyset_{uip}$	0.77
$\emptyset_{ppp}$	0.69
$\emptyset_{md}$	0.82

Source: Author's calculation

The result shows that the modes of these unknown parameters are all positive and less than one. This means that the fundamental factors are stationary. Moreover, we find that the modes of posterior distribution of discount factor and interest semi-elasticity of money demand are 0.51 and 1.04 respectively.[2] Engle et al. (2008, p.389) show that if the discount rate is close to one, the nominal exchange rate is near random walk. Since the discount factor in our case is far below one, the nominal exchange rate does not follow a near-random walk process. This implies that the black market exchange rate is not efficient in Iran.

4.2. Variance decomposition results of $s_t - f_t$

Using the random walk Metropolis-Hastings and Carter and Kohn

1. See equation (23).
2. In order to save space, we have not presented the histograms of the posterior distribution of these parameters in the paper.

algorithms, we estimate the posterior distribution of variance decomposition of $s_t - f_t$,. Figures 1 to 4 present the histograms of posterior distributions of variance decomposition of $s_t - f_t$. These figures show the contributions of the growth rate of observed fundamental, deviations from UIP, deviations from PPP and money demand shifters, respectively. We also report the mode of these posterior distributions in Table 2.

Fig 1: The contribution of variance of observable fundamental

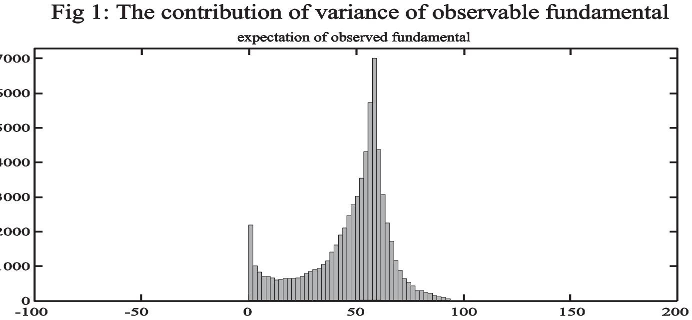

Fig 2: The contribution of variance of UIP deviations

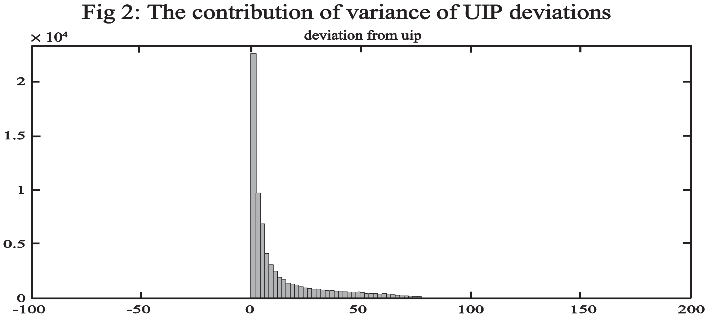

Fig 3: The contribution of variance of PPP deviations

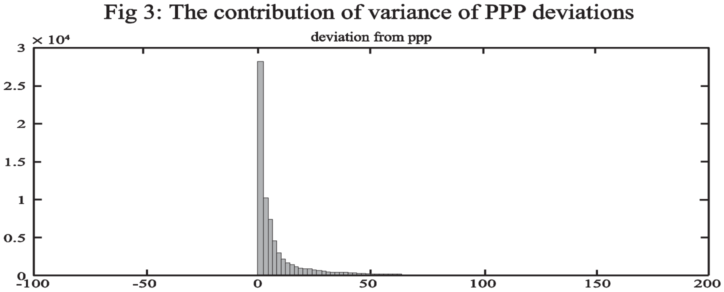

Fig 4: The contribution of variance of money demand shifter

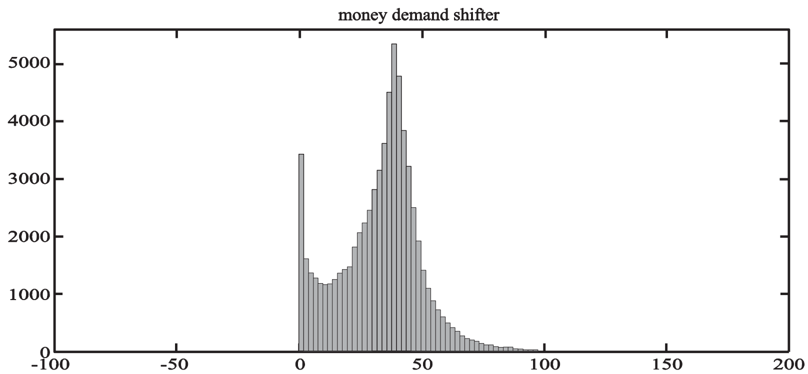

Table 2: The mode of posterior distributions of fundamental factors

Observable and unobservable fundamental factors	The mode of posterior distribution
The growth rate of observable fundamental	58.9
UIP deviations	0.99
PPP deviations	0.99
Money demand shifter	38.7

Source: Author's calculation

We observe that the contributions of deviations from UIP (risk premium) and of deviations from PPP to the variance of $(s_t - f_t)$ are small. The greatest contribution comes from the predictable component of the observable fundamental factor (58.9 percent). Moreover, we find out that the contribution of predictable component of the money demand shifter (money demand shocks) is substantial (38.7 percent). These results show that the deviation of nominal exchange rate from its long-run equilibrium can be mainly explained by both the observable fundamental factors and money demand shifter.

In other words, the observed fundamentals have the greatest contribution in explaining the nominal exchange rate movement in Iran. This result confirms the finding of previous studies which highlight the importance of monetary variables for nominal exchange rate movement in Iran. However, these variables can only explain about 59 percent of the nominal exchange rate deviation from its long run. However, in contrast to previous studies on exchange rate in Iran, we find that about 40 present of nominal exchange rate fluctuation is not explained by observable fundamental factors. Hence, this study underscores the importance of unobservable factors for describing exchange rate movement in Iran.

5. Conclusion

This paper uses a State-space model to investigate the role of observable and unobservable fundamental factors in nominal exchange rate movement in the context of monetary model to exchange rate determination. In order to achieve this goal, we estimate the present value exchange rate model that is extracted from the asset pricing approach proposed by Engel and West (2005) for Iran. In order to examine the role of fundamental factors, we estimate the variance contribution of each factor to variance decomposition of exchange rate deviation from its long run equilibrium for the period 1991:2-2011:4. The State-space model, random walk Metropolis-Hastings algorithm, Kalman filter and Carter and Kohn algorithm are used to decompose the variance contributions.

The results show that the observable fundamental growth rate and the unobserved monetary demand shocks explain about 58.9 and 38.7 percent of the deviation of nominal exchange rate from its long run, respectively. This means that about 39 percent of nominal exchange rate fluctuation cannot be explained by observable fundamentals. Hence, contrary to previous studies in Iran which have focused mainly on observable fundamental factors, we find that the unobservable fundamentals also play key role in determining the exchange rate movement in this country. This result might have important policy implications for monetary authorities in Iran. In addition, the estimation results show that the nominal exchange rate does not follow a near random walk behavior. It implies that the foreign exchange rate market in Iran is not efficient and, hence, the participants in this market might exploit past information to increase their return above the market average.

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