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Modeling Exchange Rate Behavior in Iran Using Random Differential Equations: Merton Model and NGARCH Approach

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Abstract

The main objective of this paper is to model the exchange rate behavior in Iran using random differential equations. In order to model the behavior of this market, three random differential equations have been used which include the Black-Scholes model, the Merton model, and the geometric Brownian motion with the non-linear GARCH. Also, in order to estimate the coefficients of equations, the maximum likelihood approach has been used and the drift and propagation parameters are calculated monthly and yearly for the period 2007-2017. According to the research findings, the probability of the exchange rate jump in the market is 0.87. The average rate of jump is 0.10 and the jump variance is 0.03. This confirms that the efficient-market hypothesis (EMH) does not exist in the Iranian foreign exchange market. In this paper, the non-linear GARCH model (NGARCH) based on Merton's model has been used to investigate the impact of good and bad news and positive and negative shocks. According to the results of the research, the estimated γ coefficient in the foreign exchange market is positive. That is, the exchange rate is most affected by bad news, negative shocks, and systematic risks. The numerical value of the coefficient in the currency market is 2.9, indicating that it is least affected by good news. according to the maximum likelihood function, in the Iranian currency market, the Merton model has more explanatory power than the nonlinear GARCH model and the Black-Scholes model.

Keywords: Exchange Rate, Merton Model, Black-Scholes Model, Nonlinear GARCH Model.

JEL Classification: E31, C32, E58.

1. Introduction

One of the methods of exchange rate modeling is the use of random walk theory. The randomness of exchange rate changes does not mean that the price level is irrational. If prices are reasonable, only new information will change the price.

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Therefore, the random walk theory shows that prices reflect all relevant information. Instead, if the price changes are unpredictable, the market will not be efficient. A random walk in continuous mode is converted to the Brownian process, so a random process can be used to model the exchange rate. A geometric Brownian motion or the Black Scholes model explains the random behavior of the exchange rate over time. The Black Swan model of the exchange rate in the form of a random differential equation is as follows:

$$ds_t = \mu(s.t)\, s_t + \sigma(s.t) s_t dW$$

Where, s_t is the exchange rate at time t, W is the standard Brownian motion, μ and σ are model coefficients. The standard Brownian motion is a propagation process with a mean of zero and variance σ. Brownian process has a normal distribution. Brownian motion is also continuous in time and its changes are independent. As discussed in the theoretical basis, in order to solve the above relation, Ito's relationship is used. The solution of the above differential equation is as follows:

$$dlogs_t = \left(\mu - \frac{1}{2}\,\sigma_t^2\right) dt + \sigma(s\,.t) dW$$

Based on the above relationship, the currency price differential has a normal distribution with mean ($\mu - \frac{1}{2}\,\sigma_t^2$) and variance σ_t^2. By integrating in the range from zero to T, from the two sides of the above relation and then taking anti-logarithm from its solution, we can reach the relation $S(T) = S(0)^{\left(\mu - \frac{1}{2}\sigma_t^2\right)T + \sigma W(T)}$. According to this, the currency price has a normal distribution. Given the definite currency price distribution, the maximum likelihood approach can be used to estimate the coefficients of the differential equation. One of the features of the standard Brownian relationship is that this relationship follow the Markov process. Thus, we can write the standard Brownian relationship likelihood function as the product of the likelihood density.

2. Data and Econometrics Model

The results of the estimated coefficients of the geometric Brownian motion model in the form of a random differential equation for the exchange rate show that the value of the drift parameter (μ) for the exchange rate index based on monthly data equals 0.11 and the value of propagation parameter (σ) is 0.003. Also, for annual data, the value of the drift parameter (μ) is 0.14 and the propagation parameter (σ) is 0.03. The comparison of two differential equations shows that the drift and propagation coefficients in the long run horizon are

greater than the short run horizon and the exchange rate variable has a random nature in both horizons.

In the model of Brownian geometric motion with jump (Merton model) in addition to the two parameters of drift (μ) and propagation (σ), the number of jumps per year (lambda), mean and variance of jump (delta and Muj) are added. According to the research findings, the probability of a jump in the exchange rate in the market is 0.87. The average rate of jump is 0.10 and the jump variance is 0.03. This confirms that the efficient-market hypothesis does not exist in the Iranian exchange market. Because a sudden jump under systematic risks is indicative of increase in inefficiency in the currency market.

One of the disadvantages of a geometric Brownian motion pattern is assuming fluctuation to be constant, and another problem with this pattern is the lack of attention to the role of information in the markets. While the results of empirical studies indicate randomness of returns fluctuations. In other words, the fluctuations in returns follow the GARCH process. Also, information in the market is very important in explaining the behavior of the exchange rate. Using the GARCH model and modeling the behavior of fluctuations, the above problem can be solved. In order to model the exchange rate behavior with regard to the asymmetric effects of good and bad news, a nonlinear GARCH model was used to explain the behavior of price fluctuations over time. According to the results of the non-linear GARCH model (NGARCH), the estimated γ coefficient in the foreign exchange market is positive. That is, the exchange rate is more affected by bad news, negative shocks, and systematic risks. The numerical value of the γ coefficient in the currency market is 2.9, indicating that it is least affected by good news. In general, according to the equations estimated in the Iranian currency market as well as the maximum likelihood function, the geometric Brownian model with random fluctuations (Merton) has more explanatory power than the nonlinear GARCH model and the geometric Brownian model with constant fluctuations.

3. Conclusion

The central objective of this study is to study the exchange rate behavior in Iran based on random differential equations. Accordingly, the Black-Scholes model, the Merton model, and the nonlinear GARCH model based on the Merton model are used. Examining the drift and propagation coefficients in estimated equations shows that the exchange rate in Iran has a stochastic nature. The fluctuations of this market and the jump coefficients estimated in this study confirm that the efficient market hypothesis does not exist in the Iranian foreign exchange market. This confirms that foreign exchange policy in Iran has not been able to properly determine the appropriate model for the rules of the game in this market

and the coefficient of failure in policy-making in achieving efficient market is evident based on the estimated differential equations. According to the non-linear GARCH model based on the Merton model, evidence suggests asymmetric behavior of the players in this market. So that the response of the actors to the negative and positive shocks was very different. Considering the findings of this research and the inefficiency of the Iranian foreign exchange market resulting from the Merton model, it is undoubtedly necessary to adjust and correct the exchange rate as a central and influential variable on the economy of the country. However, this adjustment and correction should be made within the framework of a corrective system and a specific modification table.

4. Results

If, regardless of this important point, changes in the exchange rate are implemented separately and without regard to other realities ruling the country's economy, it may not have favorable results and may even lead to violation of goals and inverse objectives. If it is possible to regulate and direct the mechanisms of the country's economy, in a way that lead to the creation of a conventional foreign exchange system, the adjustment of the exchange rate would automatically be carried out, and the complementary and necessary modifications would be realized in other sectors endogenously.

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