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Analysis of Foreign Exchange Rate Volatility Based on the GARCH Model

Weiyu Chen *

School of Economics and Management, Nanjing Forestry University, Jurong, China
* **Corresponding author**: Weiyu Chen (Email: 19552392968@163.com)

Abstract: At present, the foreign exchange rate is still an important factor affecting international trade transactions. Since 1990, when the yen first broke through the 150 yen mark, the yen has been depreciating continuously. At the end of April 2024, the yen fell to 158 yen to a dollar. According to research, the Fed's interest rate hike policy has impacted the yen's plunge. This paper takes this event as the starting point. It uses the GARCH model to analyze the financial time series of the dollar-yen exchange rate, to explore its volatility law, to bring certain reference significance to China's monetary policymakers. According to the empirical analysis, this paper concludes that the GARCH (1,1) model can better capture the volatility characteristics of this sequence.

Keywords: Yen exchange rate, Federal Reserve interest rate hike, Financial time series, Volatility.

1. Introduction

In the era of economic globalization, the exchange rate is an important bridge connecting the economies of various countries, its volatility pulls the lifeblood of each country and international trade transactions. If we can grasp the pattern of exchange rate fluctuations and make forecasts for the future based on historical data, it is of great significance for countries to grasp the exchange rate market and formulate monetary policies.

Exchange rate data has a strong time, and before and after the strong interdependence of data, so it is a financial time series. In the financial field, time series as an important type of data, since 1960 has been widely studied, such as the use of the ARMA linear model to capture the autocorrelation characteristics of the generation of smooth time series, but some of the time series itself is not smooth when we have to use the ARIMA model. For the study of volatility as a feature, the most common are ARCH and GARCH models.

At present, many scholars recognize the importance of the exchange rate and have carried out rich research on this. Some scholars have studied the spillover effect of the Fed's interest rate hike on China's output since 2015 and concluded that the spillover effect of the exchange rate and interest rate is relatively small, proving that China's ability to resist external risks has improved in recent years [1]. There are also scholars on the financial crisis since Japan's easing of monetary policy on the yen exchange rate research, research shows that this loose policy made the yen in the short term depreciation, but in the long term, the yen depreciation is Japan's solution to the economic problems of the most effective means, but the depreciation of the space will be affected by the U.S. policy[2]. It can be seen that the U.S. dollar as an important reserve currency in the international market, its position is significant, and the adjustment of U.S. monetary policy affects the dollar exchange rate, thus affecting the global economic situation. The volatility of financial time series is an important feature, which refers to the fluctuation of data in shorter time scales, high fluctuations tend to be accompanied by high fluctuations, and low fluctuations follow low fluctuations, thus forming peaks and troughs. Volatility characteristics in recent years have helped investors to better assess the risk of their portfolios and capture changes in the market ahead of time so that they can formulate effective management policies.

At the end of April 2024, the yen burst into the cold for a while, causing concern in the market. According to the analysis, as the yen interest rate has been kept at nearly zero level, and the Fed's aggressive interest rate hiking policy eventually contributed to the current situation of the yen's plunge. At present, China's research on foreign exchange is mainly focused on the RMB exchange rate, the study of the dollar-yen exchange rate mostly stays at the theoretical level, a few uses empirical analysis of the literature data using a distance from the present day, for the fast-changing foreign exchange market for the lack of effective proof. Therefore, this paper will borrow the yen plunge this hot financial event, the use of GARCH model on the dollar against the yen exchange rate to carry out in-depth research, to capture its volatility characteristics and its changes, for China's foreign exchange market to provide empirical evidence basis.

2. Literature Review

This study is a study of exchange rate volatility between the U.S. dollar and the Japanese yen using a GARCH-like model against the background of the current interest rate hike of the U.S. dollar and the continued depreciation of the Japanese yen, and the related literature is synthesized from the following aspects.

First, from the application level, the US dollar is the most widely circulated currency in the global currency market, while the Japanese yen is one of the three internationally recognized safe-haven currencies, and its value is usually more stable. Yanhong Zhang used the VIX index as a risk indicator to empirically analyze the yen as a safe-haven currency and proved that the VIX index is negatively correlated with the US dollar-yen exchange rate through the establishment of an error-correction model, while the impulse response analysis further proved that the yen is a better safe-haven currency than the US dollar, thus indicating that the yen exchange rate fluctuations have an important influence on the

significance of the exchange rate fluctuations for policymakers [3]. Yan Shumeng pointed out after analyzing the historical data that the international status of the dollar and the dollar exchange rate trend into a positive correlation, that is, if the dollar exchange rate continues to rise, the international status of the dollar will be enhanced, and vice versa will decline; she also used the yen in the foreign exchange reserves between 1971 and 2020 in the ratio of the data to measure the internationalization of the yen, the internationalization of its internationalization process is divided into four phases, respectively, analyze and obtain yen appreciation, exchange rate volatility, and the level of internationalization showing simultaneous fluctuations [4]. Ali, Faek Menla et al. used data on the US dollar-yen exchange rate for the period January 1998-April 2011 to explore the impact of portfolio flows on this exchange rate, concluding that the impact of portfolio flows on the exchange rate is country-dependent, and that portfolio flows from Japan to the United States, reinforcing the possibility of maintaining an appreciating state of the dollar-yen exchange rate [5]. Ishizaki, Ryuji et al. used the theory of entropy of time-varying patterns to analyze the instability of day-to-day changes in the foreign exchange rate, using the dollar-yen exchange rate for the period from 1 January 1990 to 16 April 2012 as the data, and concluded that the dollar-yen exchange rate before and after the yen's inflection points of strength-to-weakness and weakness-to-strength and The conclusion that the entropy of the time-varying pattern of USD/JPY is higher after the Lehman crisis[6]. The research of the above scholars shows that the dollar-yen exchange rate in the entire foreign exchange market has a strong research value, and exchange rate fluctuations are closely linked to the financial market situation, so it is important to explore this currency pair for insight into the market situation, and the formulation of macro policy.

Secondly, from the level of research methodology, financial time series have heteroskedasticity characteristics, researchers have found that the variance of the error in forecasting and correlation, so to portray this correlation, Engel proposed the ARCH model, but due to the need to estimate the parameters of the higher-order ARCH model is too much to affect the accuracy, Pollerslev proposed the GARCH model. Zou et al., in response to the problem that financial risk management tools are still qualitative, use the data of daily closing prices of Shanghai Stock Exchange indexes from 27 October 1997 to 8 February 2001, and use the GARCH (1, 1) model, RiskMetrics and moving average method to calculate the daily Var of Shanghai indexes and the corresponding daily return of the same day, respectively, and come up with The GARCH (1, 1) model predicts the volatility of Shanghai market returns better than RiskMetrics [7]. Wang Yiliu, to explore the change rule of exchange rate volatility since the RMB joined the SDR, chose the daily sequence of RMB against USD from 10 October 2016 to 10 October 2020 as the research data, and used the ARIMA-GARCH model to make a prediction, and compared the prediction results with a single ARIMA model, and came to the conclusion that the combined model could better capture the time series characteristics and higher accuracy [8]. Kamaruzzaman, Zetty Ain et al. applied the GARCH (1, 1) model to the Malaysian weekly stock return series and demonstrated that the two-component normal mixed GARCH (1, 1) model performs better than the normal, symmetric, and skewed Student's-GARCH model performs better [9]. From this, we can see that GARCH models are widely used and mature in financial time series such as stock returns and exchange rates.

Taken together, the current research on the dollar-yen exchange rate mainly focuses on the external environmental factors as factors affecting the exchange rate, while most of the research on the internal relationship between the two stays at the qualitative level, so it is necessary to use the model to further capture the characteristics of the exchange rate fluctuations, to prove the role of the influencing factors in a more powerful way.

3. Methods

3.1. Introduction to the Model

The GARCH model (Conditional Heteroskedasticity Model) was established by Bollerslev in 1986, which was designed to solve the problem that the order q of the ARCH model is too large in describing the variance clustering characteristics of the variables, which leads to the decrease of accuracy due to the excessive number of parameters that need to be estimated. The basic expression of the GARCH (p, q) model is:

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i E_{t-i}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 \quad (1)$$

$$E_t = \sigma_t W_t \quad (2)$$

Where E_t is the residual term in period t, W_t is white noise with mean 0 and variance 1, σ_t^2 is the variance in period t, E_{t-i}^2 is the square of the residual term in period t-i, α, β are constants.

3.2. Data Sources

The empirical object of this paper is the exchange rate of the US dollar against the Japanese yen, calculated using the Chinese yuan as the median price, hereinafter referred to as the 'exchange rate'. In order to avoid the data too far back to affect the accuracy of the prediction, this paper selects the dollar-yen exchange rate from 2015 to 31 May 2024, including two Fed rate hike cycles as the observation series, a total of 2067 exchange rate data, data from the State Administration of Foreign Exchange (SAFE).

3.3. Data Processing

Based on the analysis of the returns graph in Figure 1, it can be seen that the exchange rate has a huge change before and after 21 years, and the exchange rate stays between 100-120 before 21 years, while the exchange rate undergoes a significant increase after 21 years. Therefore, it can be inferred that there is a large fluctuation in the exchange rate of USD/JPY and the time series may be unstable.

Figure 1. Time series chart of USD/JPY exchange rate

Figure 2. USD/JPY logarithmic yield series

Since financial time series such as exchange rates generally show an inherent exponential growth trend, revealing sharp fluctuations that are not easy to analyze, the series is usually smoothed by taking the logarithmic form, which facilitates subsequent statistics and analysis. Figure 2 illustrates the time series of the logarithmic return of the United States dollar against the Japanese yen.

3.4. Descriptive Statistics

To verify the smoothness of the logarithmised time series, the ADF test is used here. The original assumption of its method is that the series has a unit root, i.e., the series is non-smooth, and if the original assumption is rejected, the series is shown to be smooth. A unit root is a time series in which the trend over time is continuous in the long run and does not converge to a stable mean.

Table 1. Stationarity test

variable	ADF statistic	1% critical value	5% critical value	result
R	-1.736302057	-3.962489343	-3.411984337	unsteady
	0.734867417	-0.01	-0.05	
DR	-45.23688568	-3.962491502	-3.411985395	steady
	0.000	-0.01	-0.05	

According to the results of the test in Table 1, it can be seen that based on the variable R, which is the original time series chart of the exchange rate, the significance p-value is 0.734867417, which is not significant, thus accepting the original hypothesis; and then the p-value of the first-order differencing is 0.000, which rejects the original hypothesis, and then the series is a smooth time series.

3.5. Establish the Mean Value Equation

The test of autocorrelation will be carried out on the premise that the series is smooth and the results of the test are all significant. After that, the lag order is determined and according to the statistics of Eviews software, it is significant at lag one.

Table 2. Parameter determination

parametric factor	Estimate	T-value	P-value
AR1	0.999826502	1667.050896	0.000
C	-0.090179178	-0.840903923	0.40040176

The final expression for the mean equation is obtained as: r_t=0.999α_{t-1}-0.090

3.6. ARCH Effect Test

In analyzing the movement of this time series of the USD/JPY exchange rate, it was found that there was a volatility clustering effect in the series, thus suggesting that the return series may have conditional heteroskedasticity, and hence the need for an ARCH model to capture this property. The F-test and Obs*R-squared statistic are used in Eviews software, which are used to measure the strength of the linear relationship between the independent and dependent variables in the model and to assess the goodness of fit of the model by testing for autocorrelation.

Table 3. ARCH effect test

F-statistic	10.43861832	Prob. F (10,2046)	0.0000
Obs*R-squared	99.85293831	Prob. Chi-Square (10)	0.0000

Through the results in Table 3, we can see that the P-values in the ARCH effect test are all less than 0.05, which means that the originally set assumptions can be rejected, and there is an ARCH effect in the equation, which allows for the establishment of a GARCH model.

3.7. GARCH Modeling

In this paper, the variance equation is first fitted from a low-order GARCH model, including GARCH (1, 1), GARCH (1, 2) and GARCH (2, 1), and the p and q values are determined according to the significance. The results found that the GARCH (1, 1) model is the most significant, indicating that the GARCH (1, 1) model is the most suitable for characterizing the volatility of the return series. Therefore, the article uses this model to fit the logarithmic yield series and the fitting results are shown in Table 4.

Table 4. GARCH (1, 1) model fitting results

parametric factor	Estimate	T-value	P-value
AR1	1.000952405	1066.146034	0
Omega	-0.090179178	-0.840903923	0.40040176
Alpha1	0.064321255	10.87712443	0
Beta1	0.92961687	155.499413	0
Shape	0.003653751	4.696913761	0

Modelling the variance from the above graph: $\sigma_t^2 = 0.003 + 0.064\alpha_{t-1}^2 + 0.929\sigma_{t-1}^2$

The fitting results in Table 4 reflect that all parameters are significant except for the Omega coefficient of the constant term of the variance equation, which is not a significant observed coefficient in the conditional heteroskedasticity analysis, and thus it can be concluded that GARCH (1, 1) fits these data well.

3.8. Residual Test

After GARCH modelling, in order to test whether there is still conditional heteroskedasticity in the residuals, it is necessary to carry out the ARCH effect test again. If the fitted GARCH model can significantly reduce or eliminate the

ARCH effect, it means that the model fits the data better and captures the volatility characteristics in the data well.

Table 5. ARCH test of residuals

F-statistic	0.577394355	Prob. F (10,2045)	0.833631518
Obs*R-squared	5.788657485	Prob. Chi-Square (10)	0.832695701

According to the results in Table 5, the P-values are all greater than 0.05, which indicates that the originally set hypothesis cannot be rejected, i.e. the model eliminates the ARCH effect in the data. Therefore, the GARCH model was successfully established.

3.9. Model Predictions

After arriving at the best GARCH model, in order to determine whether the model can effectively predict the future movement of the USD/JPY exchange rate and provide timely and forward-looking advice to monetary policymakers, the model is used to continue to forecast the data backward to 1 August 2024 and compare it with the real data to reflect the forecasting effect.

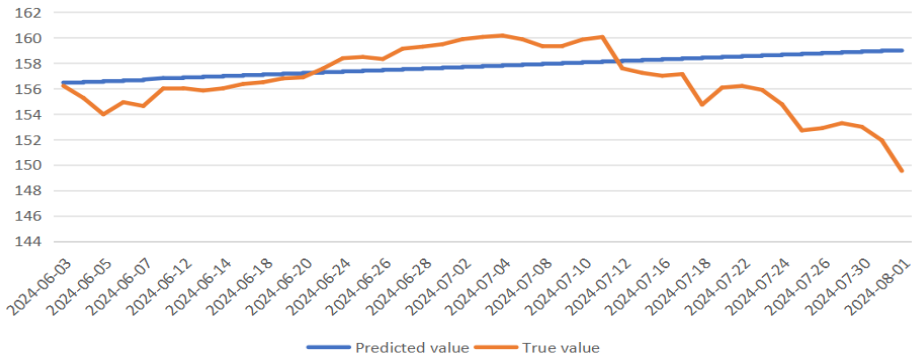

Figure 3. Forecast Comparison Chart

The results in Fig.3 show that the predicted value and the true value remain relatively close to each other around 7 June to 10 July, after which the true value maintains a downward trend while the predicted value continues to rise.

4. Conclusion

Based on the empirical analyses in the article, the following conclusions are drawn:

(1) The USD/JPY log return series is a smooth time series with the characteristic of volatility aggregation.

(2) The GARCH (1, 1) model captures the volatility characteristics of the logarithmic yield series well and maintains a relatively good accuracy in the forecasts in the following two months.

(3) According to the data in the latter section of the forecast comparison chart, we can conclude that there is a large discrepancy between the fitted value and the true value, which may be since the selected data contains the process of interspersing the Fed's rate hikes and rate cuts, and the forecasted period is in the cycle of rate hikes, and the Fed has been keeping the interest rate stable during the period, hence the discrepancy in the period.

Based on the above research, the following recommendations are made: many factors determine the Fed to change interest rates, including labor market conditions, domestic and international economic growth, and so on. When faced with a huge change in the international market, the Chinese government should turn passive into active and actively intervene in the exchange rate; at the same time, China's high level of foreign exchange reserves will affect the stability of the national currency, so the government should control the balance of payments and accelerate the transformation of the mode of economic development to cope with the challenges in the time of change in the foreign exchange market.

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