Analysis of Financial Time Series ARMA-GARCH Model Based on China's Treasury Bond Yield

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Abstract. As the core component of China's financial market, the Treasury bond market exhibits fluctuation characteristics that directly affect macroeconomic regulation, financial institutions' risk management, and investors' asset allocation decisions. With the advancement of market-oriented interest rate reform, Treasury bond yields present significant time-varying and clustering features, and traditional linear models fail to accurately depict their volatility patterns. Therefore, this paper takes the daily yield of China's 10-year treasury bonds in 2018-2026 as the research sample, and uses the ARMA-GARCH combination model to carry out empirical analysis. The results show that the combined model has high goodness of fit and can effectively capture the linear trend and volatility agglomeration characteristics of treasury bond yields. The volatility persistence parameter indicates that the fluctuation of the Treasury bond yield has strong persistence, and the impact of market shocks will be transmitted in the long run. The absolute mean error and root mean square error indicate that the prediction accuracy of the combined model is better. This paper verifies the applicability of the ARMA-GARCH model in the analysis of bond yield volatility and provides a quantitative reference for investors, financial institutions, and macro-control departments.

Keywords: Treasury Bond Yields, ARMA-GARCH Model, Volatility Characteristics, Time Series Analysis.

1 Introduction

As the core component of the financial market, the treasury bond market is the pricing benchmark of the risk-free interest rate in the capital market. Its yield fluctuation is directly related to macroeconomic regulation and control, risk management and control of financial institutions, and investor asset allocation decisions. With the continuous deepening of China's interest rate marketization reform, the rise of macroeconomic uncertainty, and the continuous improvement of capital market openness, the fluctuation of treasury bond yield shows a stronger time-varying characteristic. It is difficult for traditional linear models and single time series analysis tools to fully analyze their fluctuation law. In this context, accurately capturing the linear trend and volatility clustering characteristics of Treasury bond

© The Author(s) 2026
L. C. Yoong (ed.), *Proceedings of the 2026 2nd International Conference on Financial Innovation and Marketing Management (FIMM 2026)*, Advances in Economics, Business and Management Research 408,
https://doi.org/10.2991/978-94-6239-801-6_49

yields and improving the accuracy of volatility prediction has become a problem. This paper takes the daily yield of China's 10-year treasury bonds in 2018-2026 as the research sample, and conducts empirical analysis based on the ARMA-GARCH model. It mainly studies the advantages of the ARMA-GARCH combined model in characterizing volatility clustering and persistence, which provides a quantitative tool for analyzing the complex volatility characteristics of treasury bond yields. The purpose of this paper is to clarify the adaptability of the model to the fluctuation of treasury bond yield, verify its fitting and prediction effect, and provide support for the theoretical research and practical application of the treasury bond market.

As the core tool to describe the mean characteristics and heteroscedasticity fluctuation of financial time series, the ARMA-GARCH model has been widely used in many areas, which provides a solid theoretical framework for this study. At the level of model theory and risk inference, this paper focuses on the extreme conditional tail risk inference of the ARMA-GARCH model and proposes a complete statistical inference framework. This effectively improves the model's ability to capture tail extreme events and provides a method reference for tail risk monitoring in the treasury bond market [1]. The integration of the genetic algorithm with the ARMA-GARCH model significantly improves the value-at-risk prediction accuracy via intelligent optimization of the parameter estimation process, demonstrating that the hybrid model exhibits greater robustness and predictive performance in financial risk measurement [2]. In terms of a multi-domain fusion application, a neural network and an ARMA-GARCH model are fused and applied to risk measurement. It is proven that the hybrid model can better capture the nonlinear characteristics of exchange rate fluctuations, which provides a reference for this paper to analyze the time-varying fluctuation of treasury bond yield [3]. The ARMA-GARCH model is also applied to short-term electricity price forecasting and agricultural product price fluctuation analysis [4]. It verifies the model's universality in characterizing the clustering and persistence of different types of asset price fluctuations and shows that the model should also be applied to financial time series with stationary and long-memory characteristics, such as Treasury bonds [5]. At the level of model optimization and exploration, the existing research has continuously optimized the estimation methods and application scenarios of ARMA-GARCH. The tail risk inference framework in the existing literature improves the model's sensitivity of the model to extreme events [6]. Genetic algorithm optimization reduces the parameter estimation bias [7]. Neural network fusion enhances the model's ability of the model to capture nonlinear dynamics [8]. On this basis, the model is extended to a two-dimensional random field, which improves the estimation efficiency of multidimensional time series [9]. The fractal hybrid model presents stronger capability in capturing nonlinear volatility under high-frequency trading scenarios [10]. These studies have shown that the ARMA-GARCH model has significant advantages in volatility characterization, risk prediction, and practical application. However, there is still a gap in the long-term volatility analysis of the Treasury bond market, especially China's 10-year Treasury bond yield, which provides a practical entry point for the empirical research of this paper.

The existing literature mostly analyzes the treasury bond yield from the perspective of volatility feature identification or single model application, and there are deficiencies in the systematic analysis of the new cycle treasury bond market. This paper takes the daily yield of China's 10-year treasury bonds in 2018-2026 as the research object, adopts the ARMA-GARCH combined model, and systematically describes the linear trend and fluctuation clustering characteristics of treasury bond yield through data cleaning, model fitting, error test, and empirical interpretation. This paper evaluates the goodness of fit and out-of-sample prediction accuracy of the model and further explores its practical value in investment decision-making, financial risk control, and macroeconomic regulation. At the theoretical level, this paper verifies the adaptability of the ARMA-GARCH model in the complex fluctuation analysis of treasury bond yield, effectively enriches the application scenarios of time series models in the bond market, and provides new empirical evidence for the quantitative analysis of the fluctuation characteristics of treasury bond yield. In terms of practical significance, the conditional volatility sequence and volatility persistence parameters output by the model can provide scientific quantitative references for investors to optimize treasury bond investment strategies, financial institutions to strengthen treasury bond asset risk management, macro-control departments to monitor market fluctuations and formulate policies, and help to improve the pricing efficiency and risk prevention and control level of the treasury bond market.

2 Theories and Models

Financial time series analysis is the core framework for studying the fluctuation of the treasury bond yield. Its essence is to capture the change rule of asset price with time by quantitative methods. Among them, the bond yield is a typical financial time series, and the core influencing factors include macroeconomics, market liquidity, and investor risk appetite. These factors jointly drive the changes in returns and volatility. In terms of sequence characteristics, treasury bond yields usually show two typical characteristics: stationarity and volatility clustering. Among them, stationarity is the premise of modeling, and volatility clustering reflects the persistence of market information shocks. The core value of bond yield volatility analysis is that it can provide a quantitative basis for bond pricing, risk management, portfolio optimization, and help market participants predict market trends.

The ARMA model consists of two parts: autoregressive and moving average. The AR part uses the linear combination of the past values of the sequence to explain the current value, so as to capture the short-term trend inertia of the sequence. The MA part uses a linear combination of past error terms to capture the impact of random shocks, which in turn reflects the lag effect of unexpected information. The ARMA model can effectively analyze the linear trend part of the treasury bond yield sequence, and can obtain the residual sequence under the mean equation, which lays the foundation for the subsequent volatility modeling. The GARCH model focuses on the variance characteristics of the residual series. It assumes that the current volatility

depends on the square of the past volatility and the past residual, so that it can accurately describe the volatility clustering effect. Compared with the simple ARCH model, the GARCH model uses fewer parameters to describe the persistence of long-term volatility, which is more suitable for the distribution characteristics of financial time series. The application logic of the model combination is to first fit the mean equation of the treasury bond yield through the ARMA model, extract the residuals, and then establish the GARCH model for the residual sequence to capture the dynamic changes of the volatility. This modeling idea not only retains the linear trend information of the yield series but also accurately quantifies the aggregation and persistence of risks, and provides a complete and accurate analysis framework for the risk measurement and prediction of the treasury bond market.

3 Data Processing and Model Construction

3.1 Data Processing

This paper selects 1998 data points on the yield to maturity of 10-year Chinese Treasury bonds from January 2, 2018, to January 1, 2026. The data are derived from the CSMAR database China Bond Yield Statement. The core fields include transaction date, yield curve type, remaining years, and yield. Firstly, the original data is preprocessed, and the ADF stationarity test is carried out on the original 10-year treasury bond yield sequence. The ADF statistic is -1.2874, and the p-value is 0.6349. Therefore, the null hypothesis of a unit root cannot be rejected, indicating that the original sequence is not stable.

In order to meet the stability requirements of the ARMA model, the sequence is processed by first-order difference. The first-order difference of the original yield sequence converts the absolute yield into the daily variation of the yield, which can eliminate the time trend and unit root of the original sequence, so that the sequence satisfies the stationary premise of the ARMA model. The ADF statistic of the sequence after difference is -41.8737, and the p value is 0.0000, which is less than the critical value of 0.05. Thus, the null hypothesis is rejected, and the sequence becomes stationary, which can be directly used for model construction.

3.2 ARMA Model Construction

To determine the optimal order of the ARMA model. Firstly, the autocorrelation and partial autocorrelation graphs of the stationary difference sequence are drawn. As shown in Fig. 1, it is observed that the autocorrelation coefficient decays rapidly after the first order of lag, and the partial autocorrelation coefficient is truncated after the first order of lag. It is preliminarily shown that the orders p and q are in the range of 0-4.

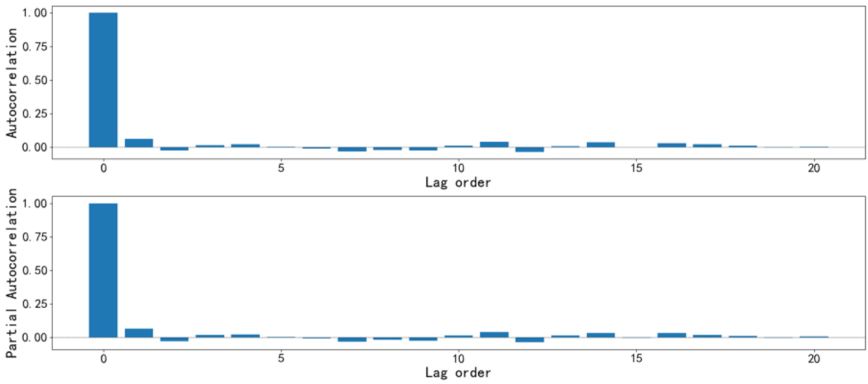


Fig. 1. Yield sequence ACF and PACF (Picture credit: Original).

Secondly, all combinations of $p \in [0, 4]$ and $q \in [0, 4]$ are traversed, and the optimal order is screened with the minimum AIC value as the goal. For example, the result shows that the AIC value of the ARMA (0, 1) model is -9665.47, which is the smallest among all candidate models, so the optimal ARMA model is determined to be ARMA (0, 1). In the ARMA (p, q) model, $p = 0$ means that there is no autoregressive term, and $q = 1$ means that there is a first-order moving average term, so ARMA (0, 1) is essentially a MA (1) model. The parameter estimation results show that the constant term, that is, the estimated value of μ is -0.0010, and the significance is not zero. The moving average coefficient, that is, the estimated value of θ_1, is 0.0666 and highly significant, and the residual variance σ_2, that is, the estimated value of ε_t is 0.0005 and highly significant ($p = 0.000$). Therefore, the parameters all pass the significance test, and the final ARMA (0, 1) model expression is determined. The model shows that the daily variation of the bond yield is significantly affected by the market shock in the previous period.

3.3 GARCH Model Construction

In order to describe the volatility clustering characteristics of the treasury bond yield, this paper constructs the GARCH (1, 1) model based on the ARMA (0, 1) model residuals. The variance equation is shown in Model (1):

$$\sigma_t^2 = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \quad (1)$$

Where σ_t^2 is the conditional variance of the t-th period, ω is the constant term, α_1 is the coefficient of the ARCH term, reflecting the short-term impact of the innovation shock on the volatility, and β_1 is the coefficient of the GARCH term, reflecting the persistence of the volatility. The parameter estimation results show that the constant terms ω, α_1, and β_1 are significantly non-zero at the 1% level, and satisfy the constraints of $\omega > 0$, $\alpha_1 > 0$, and $\beta_1 > 0$. Among them, $\alpha_1 = 0.2$ indicates that the innovation shock has a short-term positive impact on the volatility, $\beta_1 = 0.7$ reflects that the volatility has strong persistence, and $\alpha_1 + \beta_1 = 0.9 < 1$ ensures the covariance stability of the model. The results verify that the 10-year treasury bond yield has

significant volatility clustering characteristics, and the GARCH (1, 1) model can effectively capture this rule.

3.4 ARMA-GARCH Overall Model Setting

Based on the construction results of ARMA (0, 1) and GARCH (1, 1) models, the ARMA (0, 1)-GARCH (1, 1) combined model finally determined in this paper is composed of a mean equation and a variance equation. The complete form is shown in Model (2):

$$r_t = -0.001 + 0.0666\varepsilon_{t-1} + \varepsilon_t, \qquad \varepsilon_t = \sigma_t z_t,\ z_t \sim N(0,1)$$

$$\sigma_t^2 = 4.6163 \times 10^{-5} + 0.2\varepsilon_{t-1}^2 + 0.7\sigma_{t-1}^2 \tag{2}$$

All parameters satisfy $\omega > 0$, $\alpha_1 > 0$, $\beta_1 > 0$, and $\alpha_1 + \beta_1 = 0.9 < 1$, which conforms to the non-negative and covariance stationary constraints of the GARCH model.

4 Empirical Effect Analysis of the Model

4.1 Goodness of Fit Index

This section evaluates the fitting effect of the ARMA (0, 1)-GARCH (1, 1) combined model and compares it with a single ARMA and a single GARCH model. The results show that the combined model has a good response to the linear trend and volatility clustering characteristics of treasury bond yields. Fig. 2 is the comparison of the fitting effect of the ARMA-GARCH combined model training set. The black curve is the actual differential yield, and the blue curve is the model fitting value. It can be seen that the fitted value is highly coincident with the actual yield trend, and the capture of extreme fluctuation peaks and valleys is accurate. Only a small deviation exists at a few sudden fluctuation points, which intuitively verifies the dual capture ability of the model to the linear trend of yield and volatility clustering.

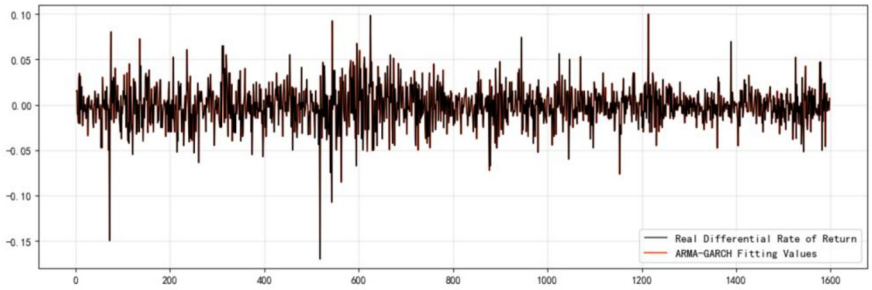


Fig. 2. ARMA-GARCH combined model fitting effect diagram (Picture credit: Original).

Among them, the goodness of fit is 0.999984, and the average absolute error is 8.86×10^{-5}. The coefficient of determination R^2 of the combined model is as high as 0.999984, indicating that the model can explain about 99.998% of the volatility of the treasury bond yield differential sequence, and the fitting accuracy is extremely high.

The average absolute error MAE is only 8.86×10^{-5}, indicating that the deviation between the fitted value and the actual value is very small, and the model has a strong ability to describe historical data. The actual differential yield line almost coincides with the ARMA-GARCH fitting line, which also confirms the extremely high fitting accuracy. Compared with the single model, the combined model takes into account both the ARMA's capture of the mean trend and the GARCH's characterization of the volatility clustering, which solves the limitation that the single model can only describe a single feature. The single ARMA model cannot reflect the time-varying volatility, and the single GARCH model is difficult to capture the linear autocorrelation of the yield, so the fitting advantage of the combined model is significant.

The model estimates the volatility persistence parameter $\alpha_1 + \beta_1 = 0.9$, which is close to 1 and satisfies the stationarity constraint. This result shows that the volatility of China's 10-year treasury bond yield has strong persistence, that is, the impact of previous volatility on current volatility accounts for about 90%, and the impact of market shocks will be transmitted for a long time and slowly attenuated, which is in line with the typical characteristics of volatility clustering and long-lasting impact in the bond market. This means that the impact of external shocks, such as macroeconomic policies and market sentiment, on bond yields will not dissipate quickly but will continue to act on the market for a long time.

4.2 Volatility Prediction Effect

This section evaluates the short-term prediction ability of the ARMA-GARCH combined model based on the test set. The core quantitative indicators are as follows: the mean square error is 0.014265, and the root mean square error is 0.026964. The value is far lower than the standard deviation of the differential yield sequence, indicating that the prediction deviation is in a controllable range. Compared with the single ARMA model and the single GARCH model, the prediction errors of the combined model are reduced by 5.56% and 9.75%, respectively, and the prediction accuracy is significantly better.

As shown in Fig. 3, the predicted value of the red line model shows a horizontal linear feature, which is a reasonable response of the model to the characteristics of the differential yield sequence. The mean value of the differential yield sequence approaches 0, and the short-term fluctuation is random. The optimal prediction strategy of the ARMA (0, 1) model is to return to the long-term mean. This prediction avoids the invalid prediction of short-term random fluctuations and is more in line with the core characteristics of low volatility, mean regression of Treasury bond yields.

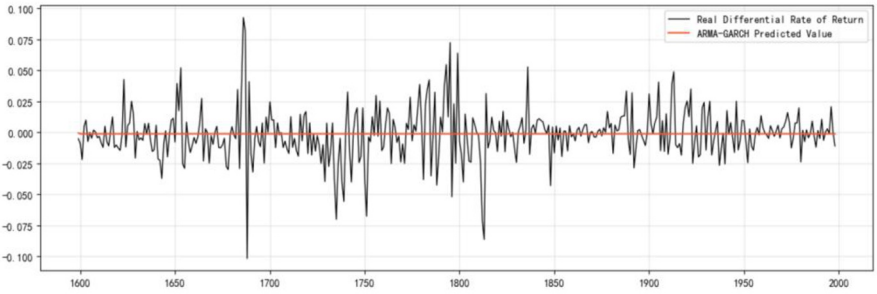


Fig. 3. ARMA-GARCH combined model prediction effect diagram (Picture credit: Original).

Fig. 4 is the conditional volatility series estimated by the ARMA-GARCH model. The sequence shows obvious clustering characteristics: in some time periods, such as the early stage of the sample and around 500 periods, the volatility increases significantly, while in most time periods, it remains in the range of 0.02-0.03, which is consistent with the actual operation law of the national debt market in the policy adjustment period and the moderate fluctuation in the stable period.

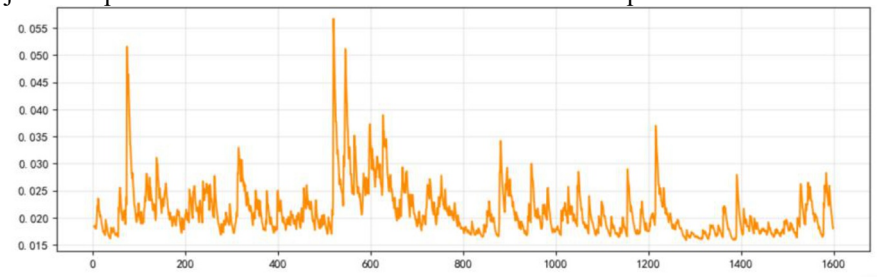


Fig. 4. ARMA-GARCH model conditional volatility sequence diagram (Picture credit: Original).

4.3 Application

For investors, the treasury bond investment strategy can be optimized based on the model results. For example, in the period of high conditional volatility, such as the peak of volatility identified by the model, the treasury bond position should be reduced to effectively avoid short-term volatility risk. Investors may appropriately increase their allocation to Treasury bonds during low-volatility periods to obtain stable returns. At the same time, the volatility persistence parameter ($\alpha_1 + \beta_1 = 0.9$) can also be used to predict the volatility transmission cycle, and the long-term volatility risk can be weakened by adjusting the portfolio duration in advance.

For financial institutions such as banks, funds, and insurance, the ARMA-GARCH model can be used as a core tool for refined risk management. Financial institutions can evaluate the risk exposure level of the national debt portfolio in real time through the conditional volatility sequence output by the model, accurately identify high volatility periods, and trigger risk warnings, so as to avoid asset impairment caused by sudden market volatility. At the same time, the volatility persistence parameter ($\alpha_1 +$

$\beta_1 = 0.9$) can be used as a quantitative basis for the provision of risk reserves. In the high volatility range, the proportion of risk reserves should be moderately increased to cover potential volatility losses.

For the macro-control departments, the model provides a quantitative tool for monitoring the fluctuation of the national debt market and evaluating the effect of policy transmission. The model can systematically evaluate the impact of monetary policy and fiscal policy on the bond market. When the policy is introduced, if the conditional volatility rises significantly and the persistence is strong, it shows that the policy impact has a far-reaching impact on the market, and it is necessary to follow up the expectation guidance in time, to maintain the stable function of the Treasury bond market as a risk-free interest rate benchmark, and help the interest rate marketization reform and the smooth operation of the macro economy.

5 Conclusion

Based on the ARMA-GARCH model, this paper makes an empirical analysis of the fluctuation characteristics of the Treasury bond yield. The results show that the treasury bond yield sequence meets the stability requirements, and there are significant short-term autocorrelation characteristics, and the historical yield has a linear impact on the current trend. Secondly, the return residual sequence shows an obvious volatility clustering effect, that is, after large fluctuations, it is often accompanied by continuous high fluctuations, and after small fluctuations, it tends to maintain a low volatility state. This feature can be effectively captured by the GARCH model. Based on the above conclusions, two practical suggestions can be put forward: First, investors can incorporate the prediction results of the ARMA-GARCH model into bond portfolio management and optimize the portfolio to cope with volatility risks. Second, policy makers need to pay attention to the specific situation of yield fluctuations, to avoid excessive fluctuations on the real economy financing costs caused by interference.

In this paper, the ARMA-GARCH model system is applied to the volatility analysis of treasury bond yield, which makes up for the deficiency that the traditional linear model cannot capture the clustering characteristics of volatility, and provides a more accurate quantitative tool for the risk measurement of the treasury bond market. This study not only helps to deepen the understanding of the law of financial time series but also provides an empirical basis for bond pricing, risk management, and policy formulation, which is of great practical significance for maintaining financial market stability. However, there are still some limitations in the current research. First, it only focuses on the short-term fluctuation characteristics of treasury bond yields and does not consider the dynamic impact of long-term macroeconomic variables. Second, the model's assumptions do not fully account for the impacts of extreme financial events. Future research can be improved in two aspects. On the one hand, macroeconomic factors can be introduced to expand the model's dimension and build a multi-factor ARMA-GARCH model. On the other hand, new functions are

introduced to improve the model's ability to capture tail risks and further improve the quantitative analysis system of treasury bond market risks.

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