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Chaos recognition and fractal analysis in the term structure of Shanghai Interbank Offered Rate

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HIGHLIGHTS

- The Shanghai interbank offered rates are studied employing chaotic and fractal analysis.
- All interest rates in SHIBOR are chaotic systems with multifractal nature.
- The smaller fluctuations of all interest rates have long-term memory property.
- There is long-term memory between SHIBOR and USD LIBOT.

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ABSTRACT

In this paper, we investigate the Shanghai Interbank Offered Rate (SHIBOR) employing the chaos recognition and fractal analysis. We find that all interest rates of SHIBOR are chaotic systems with multifractal nature. The volatilities of the short-term interest rates are larger than the medium- and long-term interest rates and the magnitudes of these fluctuations decrease with the term increases. The smaller fluctuations of all interest rates have long-term memory property. The larger fluctuations of medium- or long-term interest rates have also long-term memory property but not for those of short-term rates. Moreover, there is long-term memory property between the two interest rates of SHIBOR with one medium- or long-term, but not for both short-term interest rates. Especially, there is also long-term memory between SHIBOR and USD LIBOR. These findings are beneficial not only to understand well the SHIBOR's running but also to price accurately financial products.

1. Introduction

Interest rate plays an important role in the operations of macroeconomic activity and financial markets. The behavior of interest rate is of great concern among economists and researchers. Earlier researches focus on the main input in models of the term structure of interest rates. In most of these literatures it is assumed that the short rate follows some autoregressive process with possibly conditional heteroskedastic errors. Campbell and Shiller [1] analyze linear discrete time ARIMA processes and their implications for the term structure. Both Cox et al. [2] and Vasicek [3] models are examples from the continuous time finance which are based on univariate linear AR(1) processes with varying forms of heteroskedasticity. Hamilton [4] applies a Markov switching regime model to monthly US short-term interest rate data and finds that this model fits the data better than a linear autoregressive model. Chan et al. [5] empirically investigate the class of univariate

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autoregressive linear models. They find that there are some indications for nonlinear dynamics in interest rates, both in the mean as well as in the variance. Granger [6] reports that, by regressions on monthly data, the US short-term interest rate depends in a nonlinear way on the spread between long and short rates. Anderson [7] provides additional evidence for this type of nonlinear effects.

Pfann et al. [8] investigate nonlinear dynamics in the time series of the short-term interest rate in the United States, employing an autoregressive threshold model augmented by conditional heteroskedasticity. They suggest that nonlinear dynamics imply a form of nonlinearity in the levels relation between the long and the short rate. However, a crucially important issue in interest rate models is the long-memory property. Since in the term structure models the yield of a ten-year bond depends on expected short-term interest rates over a ten-year horizon. On the other hand, the analysis of long-memory property also becomes a fundamental question in macroeconomics and finance. In macroeconomics, since monetary policy is implemented through the setting of short-term interest rate, the term structure of interest rates is crucial to the conduction of monetary policy in most countries. Interest rates for different maturities (and durations) tend to move together. By changing short-term interest rates, monetary authorities provoke changes in longer term interest rates, which by the transmission mechanisms influence the entire economy.

To the best of our knowledge, the first to study the existence of long-term memory property in interest rates is Backus and Zin [9] who found evidence of long-term memory in the 3-month zero-coupon rate for the US, and that allowing for long-term memory in the short interest rate improves the fitted mean and volatility yield curves. Since then, others have supported Backus and Zin's results. For instance, McCarthy et al. [10] find long-memory property in US interest rates using wavelets.

In the area of econophysics, Tabak and Cajueiro contribute greatly to the researches of long-term memory in interest rate. Tabak and Cajueiro [11] find that Japanese interest rates for different maturities possess long-memory property in both mean and volatility. They verify that for long-term bonds, predictability of interest rates increases with maturity, suggesting the existence of a term premium. Furthermore, the dynamics of short-term interest rates are very different from longer term bonds, as the former are anti-persistent, which implies that the zero-interest rate policy is perceived to be temporary. Cajueiro and Tabak [12] study time-varying long-memory property for 1, 3, 5 and 10 years interest rates for the US, based on the local Whittle method, suggesting that the degree of long-term memory in the US interest rates has significantly decreased over time.

Cajueiro and Tabak [13] also find that Brazilian interest rates possess strong long-memory property in volatility, even when considering the structural break in 1999. These findings imply that the development of policy models that give rise to long-memory property in interest rates' volatility could be very useful. The long–short-term interest rates spread has strong long-memory property, which suggests that traditional tests of expectation hypothesis of the term structure of interest rates may be misspecified. Cajueiro and Tabak [14] investigate long-memory property in LIBOR interest rates, containing five international currencies: Pound sterling, US dollar, Japanese Yen, Australian dollar and the EURO. They find that the degree of long-term memory decreases with maturity, except for the interest rates of Japanese Yen and Indonesian Rupiah. Furthermore, they find that all interest rates have a multifractal nature and the degree of multifractality is much stronger for Indonesia (an emerging market).

Recently, Egorov et al. [15] study the problem of modeling the term structure of interest rates in the United States and the European Union. They provide both theoretical and empirical analysis of multi-factor joint affine term structure models for dollar and euro interest rates. Esteve et al. [16] perform an analysis of the correlation for Spanish interest rates. They find that there are linear cointegrations between long and short-term interest rates, and these cointegrating relationships have changed over time. Araújo and Cajueiro [17] investigate the forecast problem of the term structure of interest rate of Brazilian. Fernandez-Perez et al. [18] even study the problem whether the bear markets in the Spanish stock market can be forecasted by the yield curve of Spain, US and Europe etc.

The behavior of interest rate market in China, the largest emerging economy in the worldwide, deserves our further investigation. As an important sign of the Chinese interest rate marketization, Shanghai interbank offered rate (SHIBOR) has been widely concerned since its operation in October 2006. However, is SHIBOR long-range correlated? Is it a chaotic system? What is its fractal nature? What is the relationship between SHIBOR and some arbitrarily chosen LIBOR of any international currency? The investigations of all above mentioned questions are helpful for our further recognition on SHIBOR. In this paper, we will investigate these problems. The remainder of the paper is organized as follows: Section 2 introduces some methods of chaos recognition, such as Lyapunov exponent, correlation dimension, permutation entropy, and some fractal analysis, such as DCCA, DFA and MF-DFA. Section 3 shows the data and Section 4 presents the empirical results. Some explanations of findings are given in Section 5 and a brief conclusion is given in the last section.

2. Methodology

The characteristic of a chaotic sequence is represented by the singular attractor. The singular attractor can be described by three parameters. The first one is Lyapunov exponent which describes the diverging rate of two adjacent trajectories. The second is correlation dimension which describes dimension of the attractor and the third is entropy that captures the frequency of arrivals of information. All of the three parameters are invariants of the singular attractor and play important roles in describing the chaotic of a system.