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Recurrence plots analysis of the CNY exchange markets based on phase space reconstruction

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ABSTRACT

The employment of autocorrelation-based transformation to study the dynamics of the exchange rate system is meaningful because it benefits for chaotic prediction on the basis that the transformation from an exchange rate sequence to its associated autocorrelation sequence is reversible. This paper examines the influence of autocorrelation-based transformation on the systemic dynamics using exchange rates of CNY against different currencies among USD, EUR, JPY, GBP, MYR and RUB. First, we construct recurrence plots of exchange rate return sequences and autocorrelation sequences with a fixed sliding window length of 20. The recurrence quantification analysis (RQA) shows that the exchange rate return sequences exhibit lower degrees of determinism than the autocorrelation sequences. Further, by analyzing the RQA measures with bootstrap techniques and box plots, we reveal that the RQA measures of the exchange rate return systems and the autocorrelation sequence systems are mostly significant, and the vertical structures of recurrence plots of autocorrelation sequences are more sensitive to the shuffles of bootstrap techniques. Finally, we investigate the evolution of RQA measures with the changes of sliding window lengths. The analysis shows that appropriately adjusting the sliding window length can increase the systemic determinism.

1. Introduction

Since the first introduction of chaos theories by Lorenz (1965) in meteorology, researches on laws of random-looking processes which used to be regarded as noise have been highlighted. Chaos is a random-looking nonlinear deterministic phenomenon with characteristics of irregular periodicity and randomness. The application of chaos theories in economic spheres derived from the discovery of the chaos phenomenon by Stutzer (1980) in the Haavelmo macro model. Nonlinear deterministic process analysis is always one of the hottest issues for economic and financial experts to understand how the economy works. Just as its name implies, the detection of a nonlinear deterministic process can be divided into the nonlinear detection and the deterministic detection. While the nonlinear detection can be carried out with Hurst exponents by R/S analysis (Alvarezramirez, Echeverria, & Rodriguez, 2008; Cajueiro & Tabak, 2004; Yao, Lin, Liu, & Zheng, 2014) and BDS tests (Broock, Scheinkman, Dechert, & Lebaron, 1995; Brooks & Heravi, 1999; Kočenda, 2001), the determinism of nonlinear systems can be intuitively estimated with recurrence plots (Casdagli, 1997; Eckmann, Kamphorst, & Ruelle, 1987).

In descriptive statistics and chaos theories, a recurrence plot is a plot showing that measures the complexity and the determinism of a dynamical system. The texture of a recurrence plot contains the information of the systemic trajectory

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repetition which describes the structural determinism and the randomness of the reconstructed phase space. Thus a recurrence plot can reflect the autocorrelation of all the possible time scales generated in a system and is a representation of the global correlation of the system (Marwan, Romano, Thiel, & Kurths, 2007). The convenience of recurrence plot analysis makes it widely available for determinism analysis in bioscience (Carrubba, Frilot, Chesson, & Marino, 2008; Goshvarpour, 2012; Wu, 2004), climatology (Trauth, Bookhagen, Marwan, & Strecker, 2003; Yang, Wang, Bian, & Zhou, 2010) and financial fields (Addo, Billio, & Guégan, 2013; Bastos & Caiado, 2011).

Phase space reconstruction (Ma & Han, 2006) is the precondition of recurrence plot construction. The phase space reconstruction theory holds two viewpoints: first, all the dynamic information to determine the state of a system is included in the sequence evolution of the system; second, the state trajectories of univariate time series embedded in a new coordinate can preserve the most important characteristics of the original state and characterize some motion laws that cannot be described by the traditional coordinate. Abundant researches were carried out based on phase space reconstruction. Sivakumar, Jayawardena, and Fernando (2002) used phase space reconstruction approaches and artificial neural networks to understand river flow dynamics and found that not only were the major trends well captured but also the minor fluctuations reasonably preserved as well. Gao and Jin (2009) constructed a complex network from time series with nodes represented by phase space trajectories and edges determined by the trajectory distances, and found that the constructed network inherited main properties of the time series in its dynamic structure. Furthermore, some experimental results showed that the dynamic characteristics of systems can be controlled by different embedding dimensions or embedding delays. Hołyst, Żebrowska, and Urbanowicz (2001) investigated several economical exchange rates like USD/GBP, USA Treasury bond rates and the Warsaw stock index by recurrence plots, and showed how the appropriate time-delayed feedback influenced the simple chaotic economic model. Iwanski and Bradley (1998) represented that one can improve upon recurrence plot analysis by exploiting and incorporating structural characteristics of a system with different embedding dimensions.

More and more studies showed that the fluctuation modes of exchange rates are nonlinear, and the exchange rate systems possess the characteristics of complex nonlinear dynamic systems by both traditional regression models (Chinn, 1991; López-Suárez & Rodríguez-López, 2009; Priestley & Ødegaard, 2007) and nonlinear tests (Adrangi, Chatrath, & Raffiee, 2010; Pavlidis, Paya, & Peel, 2015; Stillwagon, 2016). Exchange rates from different markets can appear different dynamic characteristics. For instances, Bask (2002) showed the existence of chaos in the studies of Swedish against Deutsche Mark, ECU, USD, and Yen exchange rates while Dechert and Gencay (1992) showed no evidence of chaos in the studies of Canadian, German, Italian and Japanese monthly average spot exchange rates. Moreover, some further studies showed that exchange rates and their returns exhibited different dynamic characteristics. Lahmiri (2017) showed the existence of chaos in currency levels and the inexistence of chaos in return levels in the Moroccan exchange rate market.

The symbolic dynamics theories also provide us novel angels to understand the fluctuation modes of exchange rates. An, Gao, Fang, Huang, and Ding (2014) utilized an autocorrelation-based method to construct a symbol transfer network from a crude oil price sequence to study its fluctuation features, analyzing a one-dimensional sequence with network concepts. It led us to consider the autocorrelation of exchange rate systems which had been proved to be nonlinear.

Motivated by these previous studies, this paper applies recurrence plots to study the determinism of CNY against USD, EUR, JPY, GBP, MYR and RUB exchange rates based on phase space reconstruction. Unlike the previous studies, this paper will study the influence of autocorrelation-based transformation on the determinism of exchange rates in the CNY market as the supplement to the absent researches in this aspect and intuitively present in recurrence plot showing. Moreover, considering that the RQA (Marwan et al., 2007) provides quantitative indications for recurrence plots, this paper will briefly choose some measures to discuss the quantitative characteristics of recurrence plots of different exchange rate return sequences and the transformative sequences. Considering that the sliding window length is a key factor for autocorrelation-based transformation, this paper will investigate how the RQA measures evolve with different sliding window lengths.

The remainder of this paper is organized as follows. Section 2 discusses the methodology used in this paper, including the methods to reconstruct phase space, the choices of recurrence thresholds, and the methods to construct recurrence plots. Section 3 is the part about data description including the exchange return sequences and autocorrelation sequences formed by the original exchange sequences. Section 4 provides the result exhibitions of recurrence plots and the analysis of how the RQA measures are influenced by sliding window lengths. Finally the concluding remarks are given in Section 5.

2. Methodology

2.1. Recurrence plot construction

A recurrence plot (RP) is a tool introduced to visualize the recurrent state of multidimensional phase space of a dynamical system. Referring to Guhathakurta, Bhattacharya, and Chowdhury (2010), given one-dimensional time series $\{v_i\}_{i=1}^{N}$, we reconstruct a phase space trajectory by time delay embedding:

$$x_i = \{v_i, v_{i+\tau}, \ldots, v_{i+\tau(m-1)}\} \tag{1}$$

where m is the embedding dimension and τ is the delay.

The recurrences can be expressed by the recurrence matrix