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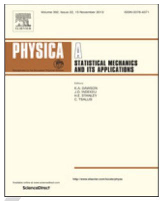

Investigating existence of chaos in short and long term dynamics of Moroccan exchange rates

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HIGHLIGHTS

- Chaotic properties of several Moroccan exchange rates are investigated.
- Stationary wavelet transform is applied to exchange rate series to obtain both its long and short term trends.
- Lyapunov exponent is estimated for each type of trend.
- The hypothesis of chaotic structure is accepted for currency levels but it is rejected for currency returns on both long and short term dynamics.
- Long and short term dynamics of some Moroccan exchange rates exhibit different chaotic patterns.

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ABSTRACT

This paper proposes a new methodology to investigate presence of chaos in exchange rate time series by combining wavelet transform and Lyapunov exponent estimation. In particular, stationary wavelet transform (SWT) is applied to exchange rate original time series for decomposition purpose. As a result, approximation and details coefficients are extracted. They are used to represent long and short term dynamics of the original exchange rate time series. Then, largest Lyapunov exponent is estimated for each type of dynamics to check for presence of chaos. Our methodology is applied to several Moroccan exchange rate time series. The empirical results show that, in general, the hypothesis of chaotic structure is accepted for currency levels but it is rejected for currency returns on both long and short dynamics. In addition, long and short dynamics exhibit different chaotic patterns in some exchange rate time series. Our approach may be useful to understand chaotic behaviour in original exchange rate time series.

1. Introduction

Chaos theory states that a chaotic system is a random-looking nonlinear deterministic process with irregular periodicity and sensitivity to initial conditions. The Lyapunov exponent; used to measure the rate of separation of two close trajectories in a dynamical system; is indeed one of the most employed techniques to assess the presence of chaotic behaviour in different problems; including analysis of short-term load [1], fault in rotating machinery [2], quasiperiodically forced electronic circuit [3], two-dimensional monopoly [4], human photoplethysmogram [5], pathological human vocal folds [6], dynamics of food chain models [7], dynamics of cardiovascular rhythms [8], and stock exchange [9,10].

The problem of studying long range dependence in exchange rates is receiving a growing attention [11–17]; however, only a limited interest has been given to testing existence of chaotic behaviour in such series [9,18–20]. In previous studies

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[9,18–20], conflicting results were found regarding the presence of chaotic behaviour in exchange rate data. For instance, an indication of deterministic chaos in twelve exchange rate series against US dollar was found in Ref. [18]. Similarly, empirical results supported the evidence of deterministic chaos in the Turkish/US exchange rate log return series [19]. However, empirical results did not indicate the presence of chaos but evidence of nonlinearity in some international exchange rates [20]. Similarly, the hypothesis of chaotic dynamics in six international exchange rates was rejected in Ref. [9].

The purpose of this study is to investigate existence of chaos in exchange rate dynamics; because of three reasons. First, only a limited interest has been given to testing existence of chaotic behaviour in exchange rate time series. Therefore, our study aims to enrich the literature in the subject. Second, the empirical results were found to be conflicting. Thus, we seek to investigate this issue by using recent data. Third, contrary to the literature, we aim to evaluate dynamic stability of short and long-term movements separately in exchange rate time series. Indeed, it is interesting to know whether chaos is present in short or in long exchange rate dynamics. In this regard, our methodology combines usage of wavelet transform of original time series to obtain its short and long movement series and estimation of largest Lyapunov exponent associated with each resulting subseries. Finally, our methodology is applied to several Moroccan exchange rate time series as Morocco is an emergent country that follows an open economy policy. Indeed, to the best of our knowledge, this is the first paper to investigate existence of chaos in Moroccan exchange rate time series; and particularly in its short and long-term dynamics.

In this study, largest Lyapunov exponent is employed since it is an appropriate measure to quantify chaos in nonlinear dynamic systems [1–10]. For instance, chaos theory assumes that the system under study follows a nonlinear and deterministic process. In addition, a chaotic system is characterized by random-like behaviour and sensitivity to initial conditions. Thus, the system is locally unstable and exhibit locally fast divergence of trajectories. Measuring the degree of divergence of trajectories can be achieved by estimating Lyapunov exponents [21]. In this work, Lyapunov exponents are estimated using methodology in Refs. [9,10,22] which is suitable to noisy dynamic systems. The stationary wavelet transform (SWT) [23] will be applied to exchange rate time series for decomposition purpose to obtain approximation coefficients; used to capture original series long-term movements; and detail coefficients; used to capture original series short-term movements. The goal is to investigate existence of chaotic oscillations; by virtue of largest Lyapunov exponent; in both approximation and detail coefficients used to characterize exchange rate time series. If a system is completely random, then its process is not predictable; whilst, if it is chaotic its process could be predicted in the short periods of time [24]. However, since chaotic systems are unstable, prediction of long run behaviour is impossible [24]. Therefore, we aim to investigate existence of chaos in long and short term behaviour of exchange rate time series. Indeed, the proposed methodology offers two important advantages: better localization of chaos, and better understanding of the dynamics of the original time series.

There are several types of wavelet transforms. The most popular ones that are widely used in engineering and scientific applications are the discrete wavelet transform (DWT), the stationary wavelet transform (SWT), and the continuous wavelet transform (CWT). The SWT is chosen because it provides more accurate estimate of the variances at each scale of decomposition, facilitates identification of salient features in signal, and recognize noise or signal rupture [25]. Indeed, since the SWT is an up-sampling process, it carries the same number of samples as the original time series. Therefore, unlike the conventional discrete wavelet transform more information is preserved after applying transform [26,27]. Besides, the CWT is useful when information regarding signal phase is needed to characterize its behaviour. In short, we present a methodology that combines SWT with largest Lyapunov exponent estimation to investigate existence of chaos in exchange rate time series. Thus, presence of regular and chaotic behaviours can be identified in exchange rate trend and short movements.

The remainder of this paper is organized as follows. In Section 2, wavelet transform and largest Lyapunov exponent estimation method are presented. The empirical results are presented in Section 3. Finally, Section 4 concludes the paper.

2. Methods

2.1. Wavelet transform

The wavelet transform [23,25] employs a scaling function $\phi(x)$ to decompose a given signal $s(x)$ into approximation and detail components. The scaling function $\phi(x)$ has two major properties; namely the orthogonality relationship and two-scale condition defined respectively as follows [25]:

$$\int \phi(x)^2 \, dx = 1, \quad \int \phi(x) \, \phi(x+i) \, dx = 0 \tag{1}$$

$$2^{-1/2}\phi\left(\frac{x}{2}-k\right) = \sum_{n=-\infty}^{+\infty} h(n-2k) \, \phi(x-n) \tag{2}$$

where $i \neq 0$, $h(\cdot)$ is a low-pass filter. The scaling function is also called a father function. In addition, a mother wavelet $\Psi(x)$ is also employed and must satisfy condition in Eq. (3a) and two-scale condition (Eq. (3b)) as follows [25]:

$$\int \psi(x) \, dx = 0 \tag{3a}$$

$$2^{-1/2}\Psi\left(\frac{x}{2}-k\right) = \sum_{n=-\infty}^{+\infty} g(n-2k) \, \varphi(x-n) \tag{3b}$$

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