Physica A 389 (2010) 2793–2804

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Fluctuation scaling of quotation activities in the foreign exchange market

Aki-Hiro Sato [a,*], Maiko Nishimura [a], Janusz A. Hołyst [b]

[a] *Department of Applied Mathematics and Physics, Graduate School of Informatics, Kyoto University, Kyoto 606-8501, Japan*

[b] *Faculty of Physics, Center of Excellence for Complex Systems Research, Warsaw University of Technology, Koszykowa 75, PL-00-662 Warsaw, Poland*

ARTICLE INFO

Article history:
Received 22 March 2008
Received in revised form 16 June 2009
Available online 8 March 2010

Keywords:
Econophysics
The foreign exchange market
Power law scaling
Taylorism
Quotation activities

ABSTRACT

We study the scaling behavior of quotation activities for various currency pairs in the foreign exchange market. The components' centrality is estimated from multiple time series and visualized as a currency pair network. The power-law relationship between a mean of quotation activity and its standard deviation for each currency pair is found. The scaling exponent α and the ratio between common and specific fluctuations η increase with the length of the observation time window Δt. The result means that although for $\Delta t = 1$ (min), the market dynamics are governed by specific processes, and at a longer time scale $\Delta t > 100$ (min) the common information flow becomes more important. We point out that quotation activities are not independently Poissonian for $\Delta t = 1$ (min), and temporally or mutually correlated activities of quotations can happen even at this time scale. A stochastic model for the foreign exchange market based on a bipartite graph representation is proposed.

1. Introduction

The complexity of economic and social systems has attracted a lot of attention from physicists recently [1–8]. Collective behavior among interacting agents shows different properties from particles governed by Newtonian laws. However, intriguing universal properties could be found and mathematical models should be considered. This movement, called socio/econo-physics, is expected to bridge a gap between physics and our societies [9].

Financial markets are complex systems which consist of many interacting agents. The progress of understanding information flows among agents sheds light on the states of financial markets, i.e. the states of market participants. The recent accumulation of a massive amount of data about financial markets due to both the development and spread of information and communication technology allows us to quantify the states of financial markets in detail [10,11]. In fact, the correlation structure of high-frequency financial time series is exhaustively and quantitatively investigated [12,13]; however, the further the dimension of multiple time series increases, the more difficult it becomes to compute cross-correlations and to recognize them.

On the other hand, several studies in both socio/econo-physics and engineering were focused on the structure of corresponding complex networks, their internal dynamics and the flows of the constituents on them [14–17]. Menezes and Barabási studied the scaling behavior of constituents' flows on several constructions such as river networks (water flows), transportation systems (car flows), and computer networks (information flows) [18,19]. As a result, scaling properties are found for flow fluctuations in such systems. This relationship is known as a fluctuation scaling or Taylor's power law [20,21]. Taylor's power law is known as the scaling relationship between the mean of populations and their standard deviation in ecological systems. The ubiquity of Taylor's power-law slopes between 1/2 and 1 suggests that there exists an underlying fundamental mechanism affecting the transportation of constituents.

* Corresponding author. Tel.: +81 75 753 5515; fax: +81 75 753 4919.
E-mail address: aki@i.kyoto-u.ac.jp (A.-H. Sato).

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doi:10.1016/j.physa.2010.03.002

Eisler and Kertész found that there is such a power-law relationship between a mean of traded volumes of stocks and their standard deviation on the New York Stock Exchange, and that the power-law exponent takes nontrivial values between 1/2 and 1 [22]. Jian et al. investigated trade volumes of stocks in the Chinese stock market [23]. They also found a non-universal scaling exponent of different fluctuations from 1/2 and 1. We think that their results provide a method to quantify the states of agents with multiple time series in the financial markets. This method is also useful to quantify the states of market participants from the viewpoint of information flows in financial markets.

The aim of this paper is to investigate information flows in the foreign exchange market (FX market) by means of quotation activities, measured as arrival rates of quotations on brokerage systems. We investigate the statistical properties of quotation activities in the FX market and quantify the total states of the market participants through fluctuation scaling.

The organization of this paper is as follows. Section 2 is a short overview of high-frequency financial data taken for our studies from the FX market. Section 3 is a brief summary of the power-law relationship (Taylor scaling) between a mean of constituents' flow on a graph and their standard deviations. In Section 4 an empirical analysis of quotation activities is performed. In Section 5 the dependence of scaling exponents on a time window length is examined, and the relationship between the states of market participants in the FX market and the scaling exponents is discussed. Section 6 is devoted to concluding remarks, and addresses possible future studies.

2. Foreign exchange market

The foreign exchange market is the largest financial market in the world. It is a network consisting of brokers, bank traders, and investors. Recent developments in Information and Communication Technology have led to the spread of electronic trading systems all over the world. As a result, many market participants can directly access the FX market by using computer terminals. Moreover, trading activities are recorded in the computer servers, which perform matching operations among quotations from the market participants, and one can analyze a large amount of data about market activities with high resolution.

In the analysis we use Time & Sales (T&S) data provided by CQG Inc. [24]. The data contain time stamps, rates, and indicators to show ask or bid quotations with a 1 min resolution. The database includes 45 currency pairs[1] consisting of 24 currencies.

Quotation activities for each currency pair are extracted from the database. Since the two-way quotation is adopted in the FX market, it is enough to count the number of the bid or ask quotations.

Let $X_{i,\Delta t}(t)$ $(i = 1, \ldots, N; t = 0, \Delta t, 2\Delta t, \ldots, (Q-1)\Delta t)$ denote the number of all incoming ask quotations for a period between t and $t + \Delta t$ for the currency pair i. $\Delta t(>0)$ denotes the time window to compute the number of quotations. Examples of quotation activities for EUR/JPY, USD/JPY and EUR/USD are shown in Fig. 1. We shall treat the FX market as a complex system consisting of 45 sites i with an unknown number of internal variables, where every site i is a corresponding currency pair from our database and its internal activity is given by the number of quotations $X_{i,\Delta t}(t)$. It is confirmed that the quotation activities exhibit an intraday pattern related to the rotation of the earth, so that they have a strong regional dependence due to entering and leaving of market participants. We focus on the short-term behavior of quotation activities under the assumption of local stationarity. In the context of financial markets, the number of quotations or transactions is known to represent a proxy variable of the latent number of information arrivals in the system [25], where the term "information" is defined by Bateson as "a difference which makes a difference" [26].

3. Theory

3.1. Fluctuation scaling

It is known [18–20,22,21,27] that for complex systems consisting of many sites i, the mean values of their internal activities $X_{i,\Delta t}(t)$

$$\langle X_{i,\Delta t}\rangle = \frac{1}{Q}\sum_{j=0}^{Q-1} X_{i,\Delta t}(j\Delta t), \tag{1}$$

and their standard deviations

$$\sigma_{i,\Delta t} = \sqrt{\frac{1}{Q}\sum_{j=0}^{Q-1}\Big(X_{i,\Delta t}(j\Delta t) - \langle X_{i,\Delta t}\rangle\Big)^2}, \tag{2}$$

[1] The database contains AUD/CHF, AUD/JPY, AUD/NZD, AUD/SGD, AUD/USD, CAD/CHF, CAD/JPY, CHF/JPY, EUR/AUD, EUR/CHF, EUR/CZK, EUR/GBP, EUR/HUF, EUR/JPY, EUR/NOK, EUR/PLN, EUR/SEK, EUR/TRL, EUR/USD, GBP/AUD, GBP/CAD, GBP/CHF, GBP/INR, GBP/JPY, GBP/NZD, GBP/USD, NZD/USD, USD/BRL, USD/CAD, USD/CHF, USD/DKK, USD/HKD, USD/HUF, USD/INR, USD/JPY, USD/KRW, USD/MXN, USD/NOK, USD/PKR, USD/PLN, USD/SEK, USD/SGD, USD/THB, USD/TRL, and USD/ZAR. These currency names are described based on ISO 4217.