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Deviations from universality in the fluctuation behavior of a heterogeneous complex system reveal intrinsic properties of components: The case of the international currency market

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HIGHLIGHTS

- Existence of semi-invariant signature in fluctuation of currency exchange rates.
- Exponents characterizing heavy tails of fluctuations have median value close to 2.
- Deviation of a currency from the inverse square law linked to macroeconomic factors.
- Exchange rate fluctuation of less developed economies show sub-diffusive nature.
- 2008 financial crisis severe enough to disrupt systemic features of currency market.

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ABSTRACT

Identifying behavior that is relatively invariant under different conditions is a challenging task in far-from-equilibrium complex systems. As an example of how the existence of a semi-invariant signature can be masked by the heterogeneity in the properties of the components comprising such systems, we consider the exchange rate dynamics in the international currency market. We show that the exponents characterizing the heavy tails of fluctuation distributions for different currencies systematically diverge from a putative universal form associated with the median value ($\simeq 2$) of the exponents. We relate the degree of deviation of a particular currency from such an "inverse square law" to fundamental macroscopic properties of the corresponding economy, viz., measures of per capita production output and diversity of export products. We also show that in contrast to uncorrelated random walks exhibited by the exchange rate dynamics for currencies belonging to developed economies, those of the less developed economies show characteristics of sub-diffusive processes which we relate to the anti-correlated nature of the corresponding fluctuations. Approaches similar to that presented here may help in identifying invariant features obscured by the heterogeneous nature of components in other complex systems.

1. Introduction

The discovery that systems at equilibrium exhibit universality near a phase transition has been a path-breaking achievement of statistical physics in the previous century [1]. However, despite considerable effort, fluctuation behavior in biological and socio-economic systems that are far from equilibrium are not yet well understood [2]. Indeed, strong

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evidence for universality of non-equilibrium transitions is still lacking [3]. The large diversity seen in non-equilibrium critical phenomena poses a major challenge for those trying to uncover general principles underlying the collective dynamics of complex systems occurring in nature and society. Such systems, apart from comprising a large number of interacting components, are often characterized by a large degree of heterogeneity in the properties of individual elements. For example, components of a complex system may exhibit qualitatively distinct dynamics. The local connection density among the elements in different parts may also greatly differ. It is known that such heterogeneity can result in deviation from universal behavior expected near phase transitions [4].

A prototypical example of a complex system with a highly heterogeneous composition is the de-centralized international trade in foreign exchange (FOREX) which constitutes the largest financial market in the world in terms of volume [5]. An advantage of studying its fluctuation behavior over that of other complex systems with many degrees of freedom is the availability of large quantities of high-resolution digital data that are relatively easily accessible for analysis [6]. The different currencies that are traded in the market are each subject to multifarious influences, e.g., related to geographical, economic, political or commercial factors, which can affect them in many different ways. Such a highly heterogeneous system provides a stark contrast to the relatively simpler systems having homogeneous composition that have typically been investigated by physicists. In particular, we can ask whether the components of a heterogeneous complex system can be expected to show universal features, i.e., phenomena independent of microscopic details, which may potentially be explained using tools of statistical physics. For the specific case of the FOREX market, establishing any robust empirical regularity will be an important contribution towards understanding the underlying self-organizing dynamics in such systems. Note that the domain of microeconomics that is concerned with the dynamics of single markets has seen accumulating evidence suggestive of universality [7]. The most robust of these relate to the nature of the heavy-tailed distributions of fluctuations in individual stock prices, as well as, equity market indices [8–11], often referred to as the "inverse cubic law" [12,13]. In contrast, macroeconomic processes have a relative paucity of such "stylized facts". Although the distribution of fluctuations in the exchange rates of currencies has been the subject of several earlier investigations [14,15], some of which have indeed reported heavy tails for different currencies, there is little agreement concerning the values of the power-law exponents characterizing such tails — not even whether they lie outside the Levy-stable regime [16–19]. This suggests that the nature of the fluctuation distribution for a particular currency could be related to some intrinsic properties of the underlying economy.

In this paper we show that there is indeed a systematic deviation from a putative universal signature – which we refer to as "inverse square law" – for the fluctuation behavior of different currencies depending on two key macroeconomic indicators, viz., the gross domestic product (GDP) per capita related to the economic performance, and the Theil index that measures the diversity of exports of the corresponding countries (see data description for details). Thus, several underdeveloped (frontier) economies exhibit currency fluctuations whose distributions appear to be of a Levy-stable nature, while those of most developed economies fall outside this regime. The median value of the exponents quantifying the heavy-tailed nature of the cumulative fluctuation distributions for all the currencies occur close to 2, i.e., at the boundary of the Levy-stable regime. Our study demonstrates how robust empirical regularities in complex systems can be uncovered when they are masked by the intrinsic heterogeneity among the individual components. We have also characterized the distinct nature of the exchange rate dynamics of different currencies by considering their self-similar scaling behavior. Our analysis reveals that while currencies of developed economies follow uncorrelated random walks, those of emerging and frontier economies exhibit sub-diffusive (or mean-reverting) dynamics.

2. Data description

The data-set we have analyzed comprises the daily exchange rates with respect to the US Dollar (USD) of $N = 75$ currencies (see Table 1) for the period October 23, 1995 to April 30, 2012, corresponding to $\tau = 6035$ days. The rate we use is the midpoint value, i.e., the average of the bid and ask rates for 1 USD against a given currency. The data is obtained from a publicly accessible archive of historical interbank market rates maintained by the Oanda corporation, an online currency conversion site [20] that is used by major corporations, tax authorities and auditing firms worldwide. The interbank (or spot) rate for a currency is the official rate quoted in the media and that apply to large transactions of 10^6 USD or higher (typically taking place between banks and financial institutions). For each day, the site records an average value that is calculated over all rates collected over a 24 h period from frequently updated sources in the global foreign exchange market, including online currency trading platforms, leading market data vendors, and contributing financial institutions. We have chosen USD as the base currency for the exchange rate as it is the preferred currency for most international transactions and remains the reserve currency of choice for most economies [21,22]. We have verified that using other base currencies lead to qualitatively similar fluctuation distributions for exchange rates.

The choice of currencies used in our study is mainly dictated by the exchange rate regime (see Table 1), which is obtained from the site [20] where we collected the exchange rates data and supplemented by information from the site of another online FOREX services company [23]. In particular, we have not considered currencies whose exchange rate with respect to USD is constant over time. Most of the currencies in our database are floating, either freely under the influence of market forces or managed to an extent with no pre-determined path. Among the remaining currencies, a few are pegged to USD or some other important currency (such as EUR), but with some variation within a band (which may either be fixed or moving in time). Note that as the EUR was introduced in January 1, 1999, i.e., within the time interval considered by us, we have used the exchange rate for the ECU (European Currency Unit) for the period October 23, 1995 to December 31, 1998.