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Self-similar characteristics of the currency exchange rate in an economy in transition

E.I. Scarlat, Cristina Stan*, C.P. Cristescu

Department of Physics, "Politehnica", University of Bucharest, 313 Spl. Independentei, 060042 Bucharest, Romania

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Abstract

In this paper, we present an analysis of the self-similar characteristics of the temporal series describing the daily exchange rate of the Romanian currency unit "Leu" (ROL) with respect to the US Dollar (USD). The relevance of this investigation consists in the exchange rate being a proper indicator for the dynamics of an economy in transition from a command-type structure towards an open market one. The time series is exhibiting self-similar cells of dimensions obeying a definite power law scaling rule that is related to different categories of economic agents. By using a crossing-type analysis based on the Hurst exponent and the frequency spectrum, five categories were detected. A simple model based on active filters with prevailing feedforward loops working close to the unstable regime, each one describing an economic agent under the stress of a hostile economic environment, is proposed for the dynamics of the fragmentation–defragmentation process. The model qualitatively reproduces the self-similarity characteristics of the currency exchange rate of an economy in transition, subjected to deep structural changes. We observe that the "in-phase evolution" of the economic agents causes the statistical self-similarity to resemble a theoretical self-similarity.

Keywords: Transition economy; Self-similar cells; Fragmentation–defragmentation dynamics; Hurst exponent

1. Introduction

About 10 years ago, the physics community discovered that methods of physics such as statistical physics and chaotic dynamics are very well suited for the analysis of the social, economic and financial problems [1,2]. Consequently, the new multidisciplinary field of econophysics emerged. It is now a clearly self-consistent field with specific methods for short- and long-run predictions for the financial and economic evolutions [3].

One of the most popular methods in the field is the multifractal analysis because the real data from different financial markets are known to exhibit self-similar properties. Multifractals were introduced in the field of economics [4,5] to surpass the shortcomings of classical theories that predict the impossibility of occurrence of precipitous events. Recently, the analysis of financial transactions has become one of the outstanding topics in econophysics [6,7] the concept of fractal structure being extended to the analysis of complex temporal processes. When the dimension of a time series is non-integer, this is associated with two specific features:

*Corresponding author.
E-mail address: cstan@physics.pub.ro (C. Stan).

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inhomogeneity—extreme fluctuations at irregular intervals, and scaling symmetries—definite relationships between fluctuations over different separation distances. In some cases, such as exchange rates, the underlying structural equations give rise to fractality [8]. The specific analysis methods are based on the Hurst exponent, correlation functions and frequency spectrum, or on more sophisticated ones, like wavelet transforms or Hölder exponent spectrum [9–11].

This paper focuses upon an interesting self-similar structure, which has been identified in the time series of the sampled daily exchange rate ROL–USD over more than 6 years. Unlike other structures reported in the literature, in our case it is not only statistically self-similar but also approaching theoretical self-similarity. We argue that the generator of such a shape is the inflationist trend, which is reaching critical values depending on the size of the economic agent and, from time to time, is limiting the clustering process of the internal market. The exponential-like growth pattern usually occurs where things are out of order. A continual payment of interest over a long period of time is practically impossible and explains why, at regular intervals, economic disturbances or breakdowns are happening. From the point of view of the researcher, inflation, and its immediate effect, currency depreciation, plays the role of an accelerator that "compresses" the time and reveals in a much shorter interval what should have happened over a quite large time horizon under quasi-normal circumstances. For this reason, economic systems under transition represent a very interesting field of research, particularly for the occurrence of events that are very improbable or even catastrophic under normal circumstances.

2. Theoretical background

One of the methods used in this work is the well-known detrended fluctuation analysis (DFA) [5,12,13] as a modified version of the random walk analysis that makes use of the fact that a power law correlated time series can be mapped to a self-similar process by integration [11,14]. The integrated time series is self-similar if the fluctuation at different observation windows scales as a power law with the window size.

In the present analysis, we skip the integration step, because apparently the data are not upper bounded. We denote $y(j)$, $j = 1,2,\ldots,N$ the genuine time series. The whole length of the series is divided into cells of equal length n that has to be changed in steps as small as possible. Beginning from one end of the series, we count M_n segments and a rest remains. Beginning from the other end, we again obtain M_n segments, different from the previous ones. By this process, the whole length of the time series is used and a partition with $2M_n$ cells is obtained.

In the next step, the trend in each cell is found as the best fit of the portion of the curve in that particular cell, by an exponential (in our case approximated as a second-order polynomial). We denote $y_{n,s}(i)$ the ordinates on these exponentials, where the subscript s refers to the cell: $s = 1,2,\ldots,2M_n$. The fluctuation in the cell s is computed using the curve $z_s(i) = y_s(i) - y_{n,s}(i)$, $i = 1,2,\ldots,n$ and is given by

$$F_s^2(n) = \frac{1}{n}\sum_{i=1}^{n}(y_s(i) - y_{n,s}(i))^2. \qquad (1)$$

The square root of the average over the $2M_n$ cells

$$F(n) = \left[\frac{1}{2M_n}\sum_{s=1}^{2M_n} F_s^2(n)\right]^{1/2} \qquad (2)$$

represents the fluctuation function.

The fluctuation $F(n)$ increases with increasing the size n of the temporal windows. If this relationship is a power type one

$$F(n) \sim n^{\alpha}, \qquad (3)$$

the time series is a self-similar process. The scaling exponent α is identical to the Hurst exponent H, if it satisfies $\alpha \in (0,1)$. The usual interpretation of the Hurst exponent follows from the relationship between the scaling parameter λ on the horizontal time axis and the scaling parameter η on the vertical axis:

$$\log \eta = H \log \lambda. \qquad (4)$$

We estimated H for the whole time series as the slope of the line relating $\log F(n)$ to $\log n$, and found a value in agreement with a fractional Brownian motion-like process. Using the box-counting method to the same time series to compute the fractal dimension D and the equation $H = 2-D$ (valid for this process [15]), we obtained a very close result for H. We consider this as good argument for using the box-counting method for computation on restricted portions of the time series where the DFA method would not be applicable.

3. Time-series structure

3.1. Data acquisition

Unlike our previous study [16], here we consider only a part of the dynamics of the ROL–USD exchange rate ranging between January 1990 and December 2001 shown in Fig. 1 (the time origin is 1 January 1990), namely, the segment bounded between the two vertical lines. It is characterized by a huge depreciation rate (average value of 188% per year—calculated between the first and the last day of the interval). As usual, "holes" from weekends and holidays being ignored, the analysis is taking into consideration trading days only.

Since 1998, when the Central Bank (CB) has announced the daily average parities of ROL with respect to the most important international currencies, we took these numerical values [17], while for the previous interval we took the inter-banking exchange rate. The absolute values of ROL are expressed in the present denominated values.

The four sharp angular points marked on the figure are delimitating several smaller exponential-like trends along the curve.

3.2. Fragmentation–defragmentation dynamics

After the fall of the totalitarian regime (December 1989) the Romanian economy was engaged in an accelerated process of fragmentation. The imported goods, especially hi-tech, invaded the internal market and

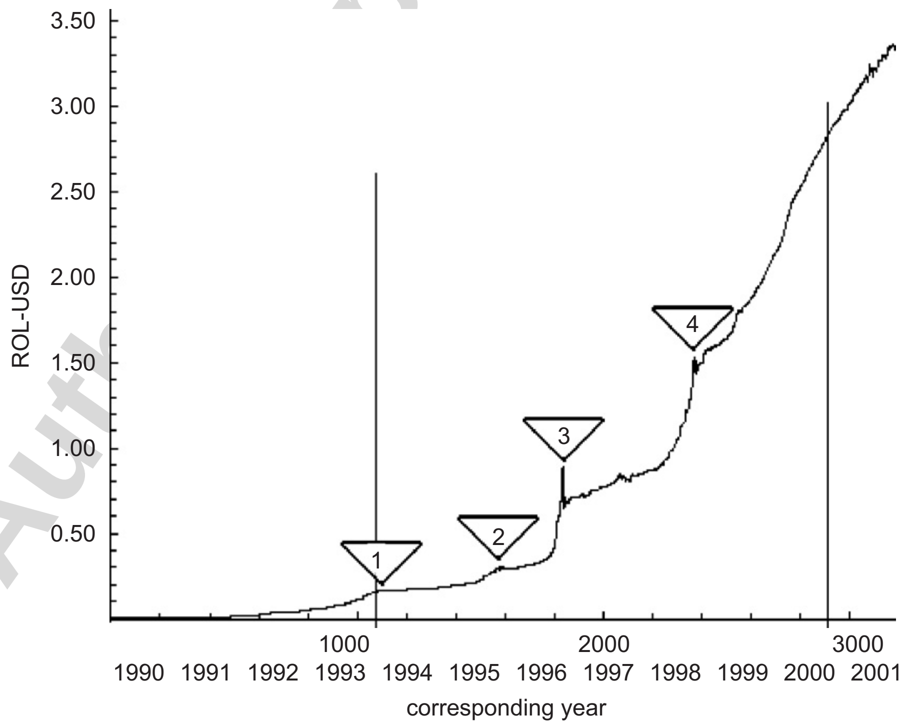

Fig. 1. ROL–USD exchange rates: absolute, denominated values $y(n)$. Four sharp angular points are marked. The vertical lines show the interval under investigation.

bridged the gap between the explosive demand and the just-in-time supply from outside. The price liberalization by the end of 1991 hastened the vanishing of a great number of the non-efficient enterprises. On the other side, the apparition of small and very small private trade-oriented companies (in 1992 and 1994 were the peaks with more than 137,000 new registrations, according to the National Institute of Statistics—NIS), result of the law of the commercial societies (end of 1990), could not by far balance the economic breakdown. Moreover, many of the newly founded agents have never really operated. In such a turbid medium and a declining economy, a major source for inflation was the "experience effect" of the undertakers, in fact of every member of the population who wanted to preserve his/her wealth. The economic laws based on demand and profit had to be fulfilled not only at the national scale (as in the command economy), but also at the scale of every economic entity. The lack of regulations was enhancing the pessimistic anticipations of the economic agents upon the sustainability of the exchange rate [18]. A (very) high inflation was distorting the picture of the deterministic relations taking place on a regular market. The net effect was the destruction of the old economic relations and total fragmentation.

The year 1994 is the beginning of the clustering processes. Foreign companies penetrated the internal market where the cheap local labour force encouraged the lohn production. The pressure on the population forced to pay the so-called "tax for inflation", cumulated with the lack of confidence in the political medium, caused a general cautiousness of the very small and small business classes (making them avoid taking risky decisions). The coming in of foreign companies represented a spillover of new technology and management [19]. Additionally, the institutions and instruments of the functional market economy were implemented and became more and more effective. Both "passive" and "active" transition periods [13] (but mostly the second) were stimulating repetitive attempts at clustering of the agents in pursuit of the critical dimensions for competitive efficiency. Over the background of economic defragmentation, the inflation contributed an additional strong pressure that led, from time to time, to disruptive breakdowns and failures or sometimes to coalescing effects. This was the beginning of a dynamical competition between fragmentation and defragmentation.

In this work, we restrict ourselves to the analysis of the lapse of time between 7 April 1994 and 15 October 2000, enclosed between the vertical lines in Fig. 1, and in the following called the clustering interval.

4. Electronic analogue model

Our analysis is based on the hypothesis that any economic agent is an intelligent entity endowed with foresight capabilities [18]. In our electronic analogue, the economic agent is modelled by an active filter with a significant feedforward loop. Besides, there is also a certain intrinsic feedback loop for everyone, reflected in the characteristic response time. These two loops are competing each other, and, in certain conditions, such as transition époques, when the regulations are far from being implemented or obeyed, the expectations of all the economic entities, ranging from the simple human being to large companies, are governed by oversized safety coefficients for the forecasting procedures related to their prospective financial plans; thus, the positive loop prevails, or, at least, it has a greater influence than in steady-state conditions. Since it is widely accepted that the internal inflation is the most important source for the depreciation of the national currency [19], we make the assumption that the exponential-like trend of the exchange rate is the consequence of an analogous exponential-like shape of a not available aggregate price index.

We shall consider a simple nonlinear model of the fragmentation–defragmentation process simulated by an electronic network connecting three identical active filters with the amplification A, the transfer coefficient of the individual feedforward loop α ($\alpha A > 1$), as shown in Fig. 2a. The main part of the filter is a differential operational amplifier with inverting and non-inverting inputs. For simplicity sake, the specific values of the auxiliary circuitry and the intrinsic feedback loops that are bringing the amplification factor to moderate values, $1 < A < 2$, are not shown. The transfer coefficient α is the result of the above-mentioned competing loops. It is known that a chain of such filters is unstable and the output increases exponentially.

We also assume a global feedback loop with the transfer coefficient β that accounts for the combined effect of exogenously and endogenously driving factors. The main exogenous factors are monetary regulations from the CB, new laws and rules for the financial market and international shocks and crises. Endogenous factors

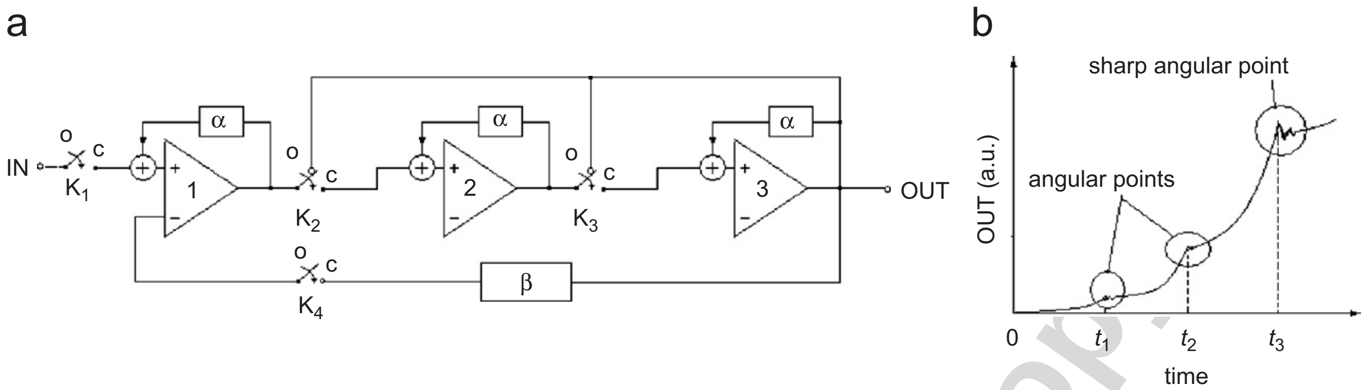

Fig. 2. The defragmentation process of three economic agents symbolized by three active filters 1, 2 and 3: the electronic equivalent set-up (a) and the computer simulation of the output (OUT) at constant input (IN) a short time after the switching on of K_4 (b).

are related to the critical size of the economic agent corresponding to its internal structure and operating mode decided by the principle of profit maximization [20,21].

Initially, the switches K_1–K_4 are open (on the "*o*" position). By denoting c_0, c_1, and c_2 the constants for the continuity of the output OUT, and keeping only the relevant terms, we consider the following sequence (see Fig. 2a):

(1) $t = 0$: the agent no.1 begins working (simulated by switching K_1 on "*c*"); the output is (with *e* the Euler's number)

$$\mathrm{OUT} = \frac{A}{\alpha A - 1}\left\{\mathrm{e}^{(\alpha A-1)t} - 1\right\}\mathrm{IN} + c_0, \quad \text{for } 0 < t \leqslant t_1, \tag{5}$$

(2) $t = t_1$: the agent no. 2 joins agent no. 1, i.e. the defragmentation is beginning; this is simulated by commuting K_2 on "*c*"; the output is of the form

$$\mathrm{OUT} \sim c_1 + \left(\frac{A}{\alpha A - 1}\right)^2 \mathrm{e}^{2(\alpha A-1)(t-t_1)}\mathrm{IN}, \quad \text{for } t_1 < t \leqslant t_2, \tag{5a}$$

(3) $3/t = t_2$: the agent no. 3 joins agents nos. 1 and 2, i.e. the defragmentation evolves (K_3 passes on "*c*"); the output is now

$$\mathrm{OUT} \sim c_2 + \left(\frac{A}{\alpha A - 1}\right)^3 \mathrm{e}^{3(\alpha A-1)(t-t_2)}\mathrm{IN}, \quad \text{for } t_2 < t \leqslant t_3. \tag{5b}$$

If we introduce a serial parameter *m*, then Eq. (5b) gets a more general form

$$\mathrm{OUT} \sim c_m + \left(\frac{A}{\alpha A - 1}\right)^m \mathrm{e}^{m(\alpha A-1)(t-t_m)}\mathrm{IN}, \quad \text{for } t_{m-1} < t \leqslant t_m. \tag{5c}$$

This sequence represents a first stage in the defragmentation process consisting in establishing of relations by serial extension over *m* entities (in our case three), when the agents are preserving their autonomy. This can be eventually followed by a second-stage generating company fusions, absorptions, stock acquisition, corporate creation, etc. The first stage is related to haphazard partnerships, consortia, common projects on strong contractual bases, while the second includes the property transfer and is affecting the structure and the size of the agent.

A simulation of the output OUT for $m = 3$ and a constant input IN is shown in Fig. 2b. For the sake of simplicity, we postulate *A* to be constant, neglecting its possible variations related to the size and type of the economic agent, as well as to the operating field.

The larger the number m, the greater the growing rate of the final output. The chain of their pessimistic anticipations is feeding the avalanche of the inflationary trend. On the other side, the authorized institutions can prevent the depreciation escalades and calm down the market by specific measures of the ''closing the feedback loop'' type. This is simulated by closing the switch K_4.

(4) $t = t_3$: K_4 passes on ''c''. While the angular points at t_1 (K_2 closed) and t_2 (K_3 closed) are corresponding to the establishing of new economic relations between agents 1 and 2, and 1, 2 and 3, respectively, the sharp angular point at t_3 is the consequence of the closing of the global feedback loop (K_4 closed). The output exhibits a sharp angular point and the growing rate of the output OUT is suddenly diminishing.

The closing of the β loop has a shocking effect. The market quickly adapts itself by shortening back the longer, more unstable chains via one of the following mechanisms:

(4a) 4a/ some of the agents are no more in business, maybe one or more fail and a new fragmentation occurs or
(4b) 4b/ the new challenges are compelling the agents to perform the second stage of the defragmentation process and they coalesce in a stronger entity of a greater size.

Thus, the shocking influence diminishes in a short time, so that m is corresponding again to a single entity, $m = 1$, irrespective of the size of the resulting economic agent. Therefore, provided that

$$y(t) \sim \mathrm{OUT}(t), \tag{6}$$

the model is consistent with the competing fragmentation–defragmentation process that characterizes the interval April 1994–October 2000.

5. Cell analysis of the data

5.1. Evidence of the self-similar structure

On the curve of the genuine data, we can identify some characteristic structures. The most expressive shapes are enclosed into boxes in order to emphasize the self-similarity (Fig. 3). The characteristic cell seems to be the image of the above-modelled non-linear dynamics. The formal trick of mapping the original bounded time

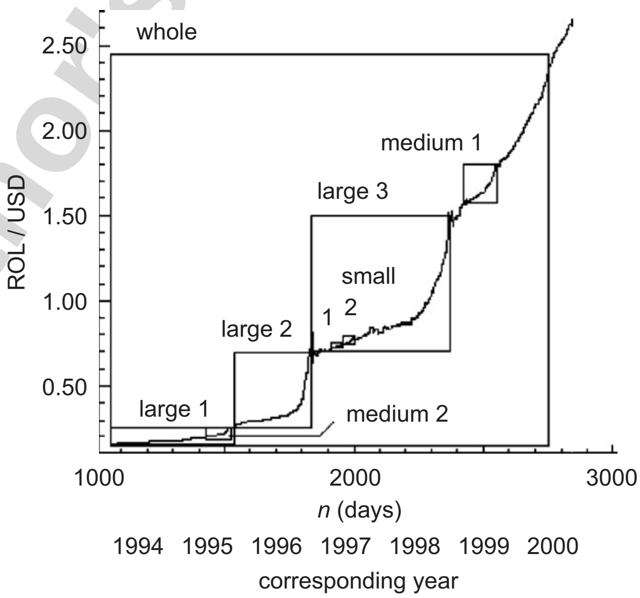

Fig. 3. The clustering interval: the exchange rate and several self-similar cells.

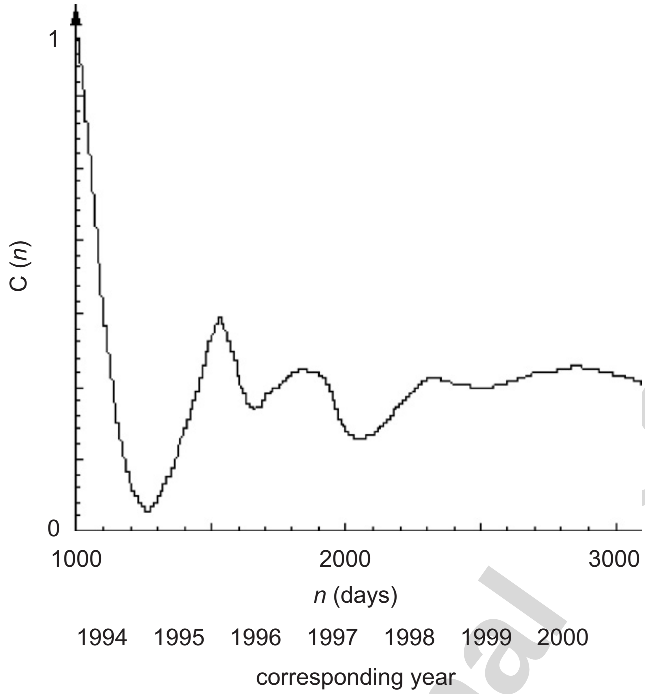

Fig. 4. The transition époque: the correlation function.

series to an integrated signal [13] is surpassed here by the natural effect of the depreciation of the national currency that characterizes the crises. While the "whole" curve is following the characteristic exponential-like trend without saturation, there are smaller cells (denoted "large", "medium" and "small") exhibiting also the exponential-like shape, but delimited by more or less sharp angular points.

During the transition, and especially after the first major fall of the gross direct product (GDP) in 1992, the repetitive trials to boost the Romanian economy [21], followed by consecutive failures, gave rise to the "stop-and-go" behaviour [22] of the transition period. The correlation function

$$C(n) = \frac{\overline{y(k)y(k+n)} - \bar{y}^2}{\overline{y^2} - \bar{y}^2} \tag{7}$$

confirms the periodic-like structure of the data (Fig. 4). Here, the bar on top denotes the average over the time series. Consequently, the existence of a self-similar structure of the exchange rate is not surprising since the foreign trade played the most important role in supporting the diversifying demand of the internal market. Moreover, in the absence of an active stock market, the currency trade is one of the most sensitive indicators that reflected the best and the quickest the current state of the economy.

5.2. *In-phase evolution and critical sizes*

Provided that the fragmentation was almost complete by the end of 1991 and no economic growth occurred in the following 2 years, by the beginning of 1994 we are faced with a particular situation of a starting time with "nil initial conditions" for the largest part of the economic agents. This might explain the "in-phase evolution" of the agents during the interval subjected to our study. The concept "in-phase" means there are no significant differences (regarding the timing of the business cycle, or the managerial and organizational development stage) between two economic entities belonging to the same size category. The sensitivity to external challenges is depending on the strength of the enterprise on the market, and we assume that the size category is a convenient measure for this strength. Definitely, we argue that the sharp angular points numbered in Fig. 1 are the consequence of the superimposed effects not only of the same environmental constraints, but also mainly of the similar way of reacting to these constraints. Table 1 presents the main events corresponding to the sharp angular points numbered in Fig. 1.

Table 1
Main events correlated with the evidence of sharp angular points

Sharp angular point	Time (days)	Date	Main event
1	Around 1100	7 April 1994	The rent law (for agricultural property)
2	Around 1500	20 November 1995	Bucharest stock exchange became operational
3	Around 1800	1 February 1997	The competition law
4	Around 2400	18 May 1999	The privatization law

Table 2
Self-similar cells

Cell		Time interval	Time length Δn (days*)	Corresponding size Δy (ROL/USD)	Hurst exponent
Whole		7 April 1994–16 October 2000	1670	2.282	0.70
Large	1	7 April 1994–15 January 1996	450	0.103	0.69
	2	15 January 1996–14 March 1997	300	0.410	0.69
	3	14 March 1997–9 April 1999	530	0.757	0.68
Medium	1	15 May 1996–5 December1996	100	0.069	0.72
	2	12 May 1999–10 December1999	145	0.297	0.71
Small	1	2 June–5 August 1997	17	0.035	0.72
	2	8 September–3 October 1997	19	0.020	0.70

*Working days.

While we could put into correspondence the above-mentioned sharp angular points with an exogenous driver that influenced the entire market, it is not clear to what extent other particular events influenced exclusively by themselves the smaller breaks, or if the dimensions of the structures were exceeding a critical chain length and the internal contradictions collapsed the entire network. For this reason, we unify the exogenous and endogenous driving factors of the feedback loop in a single one: depending on the firm size category and the market circumstances, there is a critical structure dimension that (probabilistically) enables the fragmentation process. This is consistent with similar hypotheses in the literature [23].

5.3. Self-similar cells

By direct inspection of the representation in Fig. 3, one finds out a characteristic structure of cells whose scaling is summarized in Table 2. Every cell will be characterized by its rectangular enclosure with the scale dimensions.

Following the DFA test [13] for $y(t)$, we obtain a quite significant deviation from the true Brownian random walk since the Hurst exponent has a value far enough from 0.5. The value $H = 0.70$, as calculated for the whole clustering interval, i.e. between samples no. 1100 and no. 2770. It is remarkable that at all scales, the Hurst exponent has a value around 0.70 ± 0.02, i.e. very close to the characteristic value of the whole interval (as discussed in Section 2). This is the strongest confirmation for the dominant unifractality of the series. Given the satisfactory fit of the Hurst exponent for cells of various dimensions, we can conclude that the cells we have chosen, indeed represent the fingerprint of the market activity of certain dominant categories of commercial agents.

5.4. Estimation of the scale parameters

Unlike the spectral analysis performed in a previous work [24], here a processing of the genuine series is considered. We use a high-pass filter taking the returns according to [3]

$$w(n) = \log \frac{y(n+1)}{y(n)}, \tag{8}$$

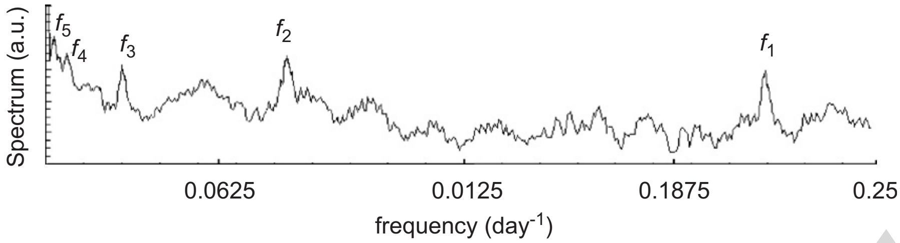

Fig. 5. The spectrum of the returns; the dominant frequencies are $f_1 \cong (4.5\text{ days})^{-1}$, $f_2 \cong (15\text{ days})^{-1}$, $f_3 \cong (40\text{ days})^{-1}$, $f_4 \cong (140\text{ days})^{-1}$, $f_5 \cong (520\text{ days})^{-1}$.

Table 3
Complementary analysis

Temporal length (days)			λ	η
Representative cell		Filtered data		
Whole	1668 (reference)	—	Reference	Reference
Large	427	525	3.20	2.26
Medium	122.5	140	3.75	2.52
Medium–small	Not found	40	3.50	2.40
Small	15.5	15	2.67	1.99
Very small	Not found	4.5	3.33	2.32
Hurst exponent $H = 0.71$			Average value 3.29	Average value 2.30

and the spectral analysis is performed on the signal $w(n)$. The spectrum in Fig. 5 clearly indicates a slightly different distribution of the dominant cycles from the representative cells for large, medium and small (frequencies f_5, f_4 and f_2) and, more important, it completes the gaps in the left column of Table 3 with the frequency f_3 that corresponds to a cycle of 40 days (medium–small). Simultaneously, it reveals a new (very small) value of a 4.5-day cycle (f_1 in Fig. 5), which is not expected to be observed on the genuine series due to the inherent noise. This might be the influence of the weekly activities of the individual and familial entities.

The frequencies f_2, f_4, and f_5 are fitting the statistics of the small, medium and large representative cells, respectively.

The parameter λ in the third column of Table 3 is estimated from the filtered data and the representative cells in Fig. 3. Using the Hurst exponent given by equation $H = 2–D$, with D computed by the box-counting method, we can estimate the scale parameter η with the values given in the forth column of the table. This parameter can be interpreted as an indicator of the critical pressure exerted by inflation.

5.5. *Statistics of defragmentation*

The statistics of the number of active economic agents (according to the EUROSTAT classification) reveals the almost doubling of the number of individual and familial entities between 1994 and 2000, while the number of enterprises reached the peak in 1997 and decreased slowly after that. In fact, at a larger scale, one can state that in the whole period 1994–2000 the total number of active companies only fluctuated around a plateau value of 316,000 since in 1993 there were less than 250,000, and only in 2003 a significant increase to a little more than 349,000 with respect to the previous year (315,000 by the end of 2002) was recorded [25].

The obligation to raise the registered capital by a factor of ten (1997) produced effects in 1998, when the number of active companies diminished by more than 10,000 units. The fraction of very small companies diminished from 93.5% in 1994 to 90.3% in 2000, while all other categories raised their number: small—from 5.4% to 7.7%, medium—from 0.9% to 1.6%, and big—from 0.2% to 0.5%. Much more spectacular is the evolution of their weight in the total turnover (see Fig. 6). The market competition was sorting out the overwhelming, and, in some sense, unjustified number of companies, by forcing them to choose between any

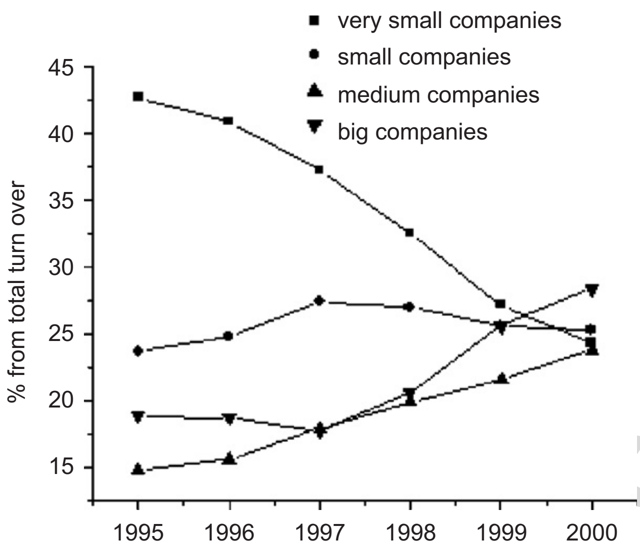

Fig. 6. The weight of the companies in total turnover according to the category.

kind of economic development (including fusion, absorption, selling, reorganization, etc.), or failure. All of the categories converge (at least by the end of the preceding millennium) toward the equal weight of 25% from total turnover.

It is worth noting that both the number and the importance of the very small firms decreased as the consequence of the defragmentation processes. According to the size, the data confirm the increase of big and medium companies to the disadvantage of the very small firms and support the defragmentation hypothesis.

6. Conclusions

Unlike a large part of the literature dealing with the stable economic systems, and thus rejecting the trends and preserving only the returns, our attention is focused onto the global dynamics of an economy in transition as reflected in the exchange rate of national currency. We observe that due to the "in-phase" evolution of the economic agents, the statistical self-similarity of the time series of the daily exchange rate ROL–USD resembles a theoretical self-similarity. The huge inflation strongly biases the exchange rate and makes detectable the dominant, monofractal structure in the time series. The identification of self-similar cells that are related to different categories of economic agents is used in the study of the fragmentation–defragmentation process. A crossing-type analysis based on the Hurst exponent and the frequency spectrum revealed five representatives categories. A simple model for the dynamics of the fragmentation–defragmentation process, based on an electronic network where the central entity, an active filter with prevailing feedforward loop and working close to an unstable regime describing an economic agent, is proposed.

We find that the model qualitatively reproduces the self-similarity characteristics of the currency exchange rate under these particular circumstances.

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