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Long Memory in the Ukrainian Stock

LONG MEMORY IN THE UKRAINIAN STOCK MARKET AND FINANCIAL CRISES

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Abstract

This paper examines persistence in the Ukrainian stock market during the recent financial crisis. Using two different long memory approaches (R/S analysis and fractional integration) we show that this market is inefficient and the degree of persistence is not the same in different stages of the financial crisis. Therefore trading strategies might have to be modified. We also show that data smoothing is not advisable in the context of R/S analysis.

Keywords: Persistence, Long Memory, R/S Analysis, Fractional Integration

JEL Classification: C22, G12

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1. INTRODUCTION

As a result of the recent financial crisis the relevance of traditional models based on the efficient market hypothesis (EMH) has been questioned. An alternative paradigm is the so-called fractal market hypothesis (FMH – see Mandelbrot, 1972, and Peters, 1994), according to which stock prices are not linear and the normal distribution (a basic assumption of the EMH) cannot be used to explain their movements given the presence of "fat tails". Within this framework one of the key characteristics of financial time series is their persistence or long memory.

This paper uses two different approaches (i.e. R/S analysis and fractional integration) to estimate persistence in the Ukrainian stock market. In particular, we show that this feature is not the same at different stages of the financial crisis of 2007-2009. We also show that data smoothing does not improve the R/S method.

The layout of the paper is the following. Section 2 describes the data and outlines the Hurst exponent method as well as the I(d) techniques used. Section 3 presents the empirical results. Section 4 provides some concluding remarks.

2. DATA AND METHODOLOGY

The R/S method was originally applied by Hurst (1951) in hydrological research and improved by Mandelbrot (1972), Peters (1991, 1994) and others analysing the fractal nature of financial markets. Compared with other approaches it is relatively simple and suitable for programming as well as visual interpretation.

For each sub-period range R (the difference between the maximum and minimum index within the sub-period), the standard deviation S and their average ratio are calculated. The length of the sub-period is increased and the calculation repeated until the size of the sub-period is equal to that of the original series. As a result, each sub-period is determined by the average value of R/S. The least square method is

applied to these values and a regression is run, obtaining an estimate of the angle of the regression line. This estimate is a measure of the Hurst exponent, which is an indicator of market persistence. More details are provided below.

1. We start with a time series of length M and transform it into one of length N=M-1 using logs and converting stock prices into stock returns:

$$N_i = \log \frac{Y_{t+1}}{Y_t}$$
, $t = 1,2,3,...(M-1)$ (1)

2. We divide this period into contiguous A sub-periods with length n, so that $A_n = N$, then we identify each sub-period as I_a , given the fact that $a = 1, 2, 3, \ldots, A$. Each element I_a is represented as N_k with $k = 1, 2, 3, \ldots, N$. For each I_a with length n the average e_a is defined as:

$$e_a = \frac{1}{n} \sum_{k=1}^{n} N_{k,a}, \quad k = 1,2,3,...N, = 1,2,3...,$$
 (2).

3. Accumulated deviations $X_{k,a}$ from the average e_a for each sub-period I_a are defined as:

$$X_{k,a} = \sum_{i=1}^{k} (N_{i,a} - e_a).$$
 (3)

The range is defined as the maximum index $X_{k,a}$ minus the minimum $X_{k,a}$, within each sub-period (I_a):

$$R_{la} = \max(X_{k,a}) - \min(X_{k,a}), \ 1 \le k \le n. \tag{4}$$

4. The standard deviation S_{Ia} is calculated for each sub-period I_a :

$$S_{la} = \left(\frac{1}{n}\right) \sum_{k=1}^{n} (N_{k,a} - e_a)^2$$
 (5)

5. Each range R_{Ia} is normalized by divi

obtained adjacent sub-periods of length n. Thus, the average R/S for length n is defined as:

$$(R/S)_n = (1/A) \sum_{i=1}^{A} (R_{ia}/S_{ia}).$$
 (6)

- 6. The length n is increased to the next higher level, (M 1)/n, and must be an integer number. In this case, we use n-indexes that include the initial and ending points of the time series, and Steps 1 6 are repeated until n = (M 1)/2.
- 7. Now we can use least square to estimate the equation log (R/S) = log (c) + Hlog (n). The angle of the regression line is an estimate of the Hurst exponent H. This can be defined over the interval [0, 1], and is calculated within the boundaries specified in Table 1.

[Insert Table 1 about here]

An important step in the R/S analysis is the verification of the results by calculating the Hurst exponent for randomly mixed data. In theory, these should be a random time series with a urst exponent equal to 0.5. In this paper, we will carry out a number of additional checks, including:

- Generation of random data;
- Generation of an artificial trend (persistent series);
- Generation of an artificial anti-persistent series.

In order to analyse persistence, in addition to the Hurst exponent and the R/S analysis we also estimate parametric/semiparametric models based on fractional integration or I(d) models of the form:

$$(1 - L)^{d} x_{t} = u_{t}, \quad t = 0, \pm 1, ...,$$
 (9)

where d can be any real value, L is the lag-operator ($Lx_t = x_{t-1}$) and u_t is I(0), defined for our purposes as a covariance stationary process with a spectral density function that is

positive and finite at the zero frequency. Note that H and d are related through the equality H = d - 0.5.

In the semiparametric model no specification is assumed for u_t, while the parametric one is fully specified. For the former, the most commonly employed specification is based on the log-periodogram (see Geweke and Porter-Hudak, GHP, 1983). This method was later extended and improved by many authors including Künsch (1986), Robinson (1995a), Hurvich and Ray (1995), Velasco (1999a, 2000) and Shimotsu and Phillips (2002). In this paper, however, we will employ another semiparametric method: it is essentially a local 'Whittle estimator' in the frequency domain, which uses a band of frequencies that degenerates to zero. The estimator is implicitly defined by:

$$\hat{d} = \arg\min_{d} \log \overline{C(d)} - 2d \frac{1}{m} \sum_{s=1}^{m} \log \lambda_{s} , \qquad (10)$$

$$\overline{C(d)} = \frac{1}{m} \sum_{s=1}^{m} I(s) \quad {2d \atop s}, \qquad \lambda_s = \frac{2\pi s}{T}, \qquad \frac{m}{T} \to 0,$$

Velasco, 1999b, Velasco and Robinson, 2000; Phillips and Shimotsu, 2004, 2005 and Abadir et al. (2007).

Estimating d parametrically along with the other model parameters can be done in the frequency domain or in the time domain. In the former, Sowell (1992) analysed the exact maximum likelihood estimator of the parameters of the ARFIMA model, using a recursive procedure that allows a quick evaluation of the likelihood function. Other parametric methods for estimating d based on the frequency domain were proposed, among others, by Fox and Taqqu (

same time the decision to restructure the AIG debt led to better investment expectations of market participants and to a fall of the VIX index to 39.33 (Figure 2).

Also important is the choice of the interval of the fluctuations to analyse, i.e. 5, 30, 60 minutes, one day, one week, one month. We decided to focus on the 1-day interval, because higher frequency data generates significant fluctuations of fractals, and lower frequency data lose their analytical potential.

We incorporate data smoothing into the R/S analysis and test the following hypothesis: data smoothing (filtration) lowers the level of "noise" in the data and reduces the influence of abnormal returns; smoothing makes the data closer to the real state of the market.

We use the following simple methods:

- 1) Smoothing with moving averages (simple moving average and weighted moving average with periods 2 and 5);
- 2) Smoothing with the Irwin criterion.

The analysis is conducted for the Ukrainian stock market index (UX) over the period 2008-2013. Overall we analysed 1300 daily returns. As a control group we chose daily closes of UX (unfiltered data) and a set of randomly generated data. The estimates of the Hurst exponent for the mixed data sets are used as a criterion for the adequacy of the results.

[Insert Figures 3 – 8 about here]

The first stage is the visual analysis of both unfiltered and filtered data. The results are presented in Figures 3 - 8. The behaviour of the series does not change dramatically after filtering (smoothing), but the level of "noise" decreases. In terms of fractal theory, visual inspection reveals a decrease of the fractal dimension.

To confirm that the properties of the time series are the same and we only neutralise the level of unnecessary "noise", we filtered randomly generated data sets for which the fractal dimension should remain the same. However, visual inspection (see Figures 6 - 8) shows that the fractal dimension of the randomly generated data set also changes after filtering.

To corroborate the visual analysis we calculate the Hurst exponent for each type of filter.

[Insert Table 2 about here]

As can be seen from Table 2, filtering the data leads to over-estimating the Hurst exponent. The longer the averaging period (the bigger the level of filtering) the higher the Hurst exponent is, indicating dependency of the latter on the former.

Irwin's method also generates overestimates of the Hurst exponent and therefore is inappropriate as well. Overall, it appears that data smoothing artificially increases the Hurst exponent, and therefore further calculations will be based on the original data sets.

One more possible modification of the R/S analysis is the use of aliquant numbers of groups, i.e. computing the Hurst exponent for all possible groups. The results are presented in Table 3.

[Insert Table 3 about here]

Both the real financial data and the randomly generated ones suggest that the use of aliquant numbers of groups leads to overestimates of the Hurst exponent. Nevertheless, using them might be appropriate in the case of small data sets, but a correction of 0.03 - 0.05 should be made depending on the value of the Hurst exponent (the bigger it is the bigger the correction should be). Given these results, the standard methodology will be used below to estimate the Hurst exponent.

3. EMPIRICAL RESULTS

As a first stage of the analysis we estimate persistence of two Ukrainian stock market indices over the full sample (UX: 2008-2013, PFTS: 2001-2013). The results in Table 4 provide evidence of persistence and long memory.

Next, we estimate persistence during the financial crisis. We checked different window sizes and found that 300 (close to one calendar year) is the most appropriate on the basis of the behaviour of the Hurst exponent: for narrower windows its volatility increases dramatically, whilst for wider ones it is almost constant, and therefore the dynamics are not apparent.

Having calculated the first value of the Hurst exponent (for example, that for the date 13.07.2007 corresponds to the period from 21.04.2005 till 13.07.2007), each of the following ones is obtained by shifting forward the "data window". The chosen size of the shift is 10, which provides a sufficient number of estimates to analyse the behaviour

increar

Figures 11 and 12 display respectively the correlograms and periodograms of each series.

[Insert Figures 10 -12 about here]

They suggest that the UX index is non-stationary. This can also be inferred from the correlogram and periodogram of the series. Stock returns might be stationary but there is still some degree of dependence in the data. Finally, the correlograms of the absolute and the squared returns also indicate high time dependence in the series.

Table 5 reports the estimates of d based on a parametric approach. The model considered is the following:

$$y_t = + t + x_t$$
, $(1 - L)^d x_t = u_t$, $t = 1, 2, ...$,

where y_t stands for the (logged) stock market prices, assuming that the disturbances u_t are in turn a) white noise, b) autoregressive (AR(1), and c) of the Bloomfield-type, the latter being a nonparametric approach that produces autocorrelations decaying exponentially as in the AR case.

[Insert Table 5 about here]

We consider the three standard cases of i) no regressors (==0 above), ii) with an intercept (i.e., ==0), and iii) with an intercept and a linear time trend. The most relevant case is the one with an intercept. The reason is that the t-values imply that the coefficients on the linear time trends are not statistically significant in all cases, unlike those on the intercept. We have used a Whittle estimator of d (Dahlhaus, 1989) along with the parametric testing procedure of Robinson (1994).

The results indicate that for the log UX series the estimated value of d is significantly higher than 1 independently of the way of modelling the I(0) disturbances. As for the absolute and squared returns, the estimates are all significantly positive, ranging between 0.251 and 0.313.

[Insert Figure 13 about here]

Figure 13 focuses on the semiparametric approach of Robinson (1995b), extended later by many authors, including Abadir et al. (2007). Given the nonstationary nature of the UX series, first-differenced data are used for the estimation, then adding 1 to the estimated values to obtain the orders of integration of the series. When using the Abadir et al.'s (2007) approach, which is an extension of Robinson's (1995) that does not impose stationarity, the estimates were almost identical to those reported in the paper, and similar results were obtained with log-periodogram type estimators. Along with the estimates we also present the 95% confidence bands corresponding to the I(1) hypothesis for the UX data and the I(0) hypothesis for the absolute/squared returns. We display the estimates for the whole range of values of the bandwidth parameter m=1,...,T/2. It can be seen that the values are abov

market indices, namely the PFTS and UX indices. The evidence suggests that this market is inefficient and that persistence was not constant over time; in particular, it increased during the recent financial crisis, when the market became less efficient/more predictable and more vulnerable to market anomalies. This created the opportunity for profitable trading strategies exploiting the January, day of the week, end of the month, holidays effects and other market anomalies, or, alternatively, based on following trends

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Tables and Figures

Table 1: Hurst exponent interval characteristics

Interval	Hypothesis	Distribution	«Memory» of	Type of	Trading
H < 0,5	Data is fractal, fractal market hypothesis is confirmed	"Heavy tails" of distribution	series Antipersistent series, negative correlation in instruments	process Pink noise with frequent changes in direction of	Strategies Trading in the market is more risky for an individual participant
0			value changes	price movement	
H=0,5	Data is random, Efficient market hypothesis is confirmed	Movement of asset prices is an example of the random Brownian motion (Wiener process), time series are normally distributed	Lack of correlation in changes in value of assets (memory of series)	White noise of independen t random process	Traders cannot "beat" the market with the use of any trading strategy
0,5 < H 1	Data is fractal, fractal market hypothesis is confirmed	"Heavy tails" of distribution	Persistent series, positive correlation within changes in the value of assets	Black noise	Trend is present

Table 2: Hurst exponent estimation for different variants of data filtration

	Unfiltered	SMA (2)	SMA (5)	WMA (2)	WMA (5)	Irwin
UX (daily returns)	0.67	0.69	0.73	0.69	0.73	0.70
UX (mixed data)	0.54	0.53	0.54	0.52	0.53	0.49
Random data	0.51	0.56	0.63	0.55	0.61	0.52
Mixed random data	0.53	0.52	0.51	0.51	0.51	0.54

Table 3: Hurst exponent estimates with standard methodology (aliquot number of

groups) and modified (aliquant number of groups) for different data sets

	UX (close)	Random	UX (SMA 5)	UX (WMA 5)	UX (Irving)
Standard	0.67	0.51	0.73	0.73	0.7
Modified	0.7	0.55	0.78	0.77	0.73

Table 4: Full-sample analysis of Ukrainian stock market

persistence

	PFTS	UX
Hurst exponent	0,665	0,667
Hurst exponent (mixed data)	0,53	0,54

Table 5: Estimates of d and 95% confidence intervals

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Series: UX.DAT No regressors		An intercept	A linear time trend	
14 ft - 1	0.999	1.124	1.123	
White noise	(0.966, 1.036)	(1.091, 1.162)	(1.089, 1.162)	
15 (1)	1.371	1.100	1.099	
AR (1)	(1.311, 1.452)	(1.049, 1.161)	(1.048, 1.152)	
5	0.994	1.099	1.098	
Bloomfield-type	(0.944, 1.062)	(1.056, 1.151)	(1.051, 1.151)	
SQUARED returns	No regressors	An intercept	A linear time trend	
	0.278	0.276	0.274	
White noise	(0.245, 0.316)	(0.243, 0.314)	(0.241, 0.313)	
A D (4)	0.266	0.261	0.257	
AR (1)	(0.218, 0.322)	(0.209, 0.311)	(0.203, 0.311)	
	0.254	0.251	0.249	
Bloomfield-type	(0.211, 0.328)	(0.207, 0.334)	(0.199, 0.334)	
ABSOLUTE returns	No regressors	An intercept	A linear time trend	
1.00	0.268	0.259	0.258	
White noise	(0.239, 0.300)	(0.229, 0.292)	(0.228, 0.291)	
15 (1)	0.326	0.311	0.309	
AR (1)	(0.281, 0.372)	(0.264, 0.363)	(0.261, 0.362)	
	0.334	0.313	0.312	
Bloomfield-type	(0.291, 0.424)	(0.261, 0.376)	(0.261, 0.375)	

Figure 1 – Periodisation of financial crisis 2007-2009

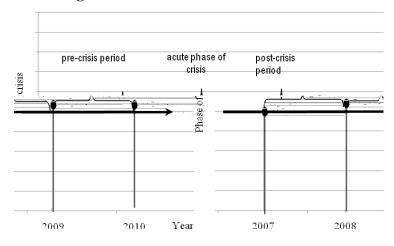


Figure 2 – Dynamics of the VIX Index in 2007-2010

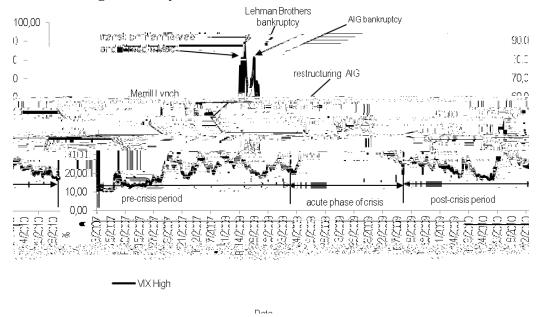
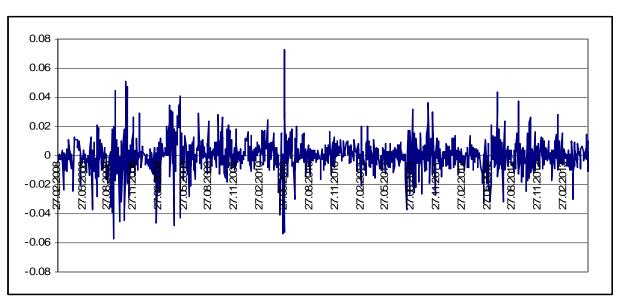


Figure 5
Visual interpretation of filtered and unfiltered UX data: Irwin filtration

a) Unfiltered UX data



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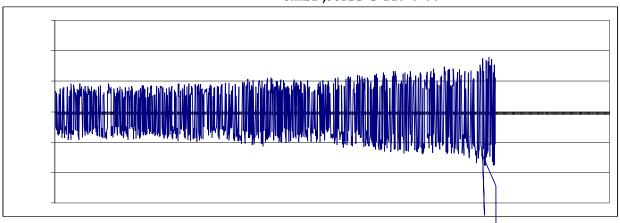
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Figure 6

Visual interpretation of filtered and unfiltered randomly generated data: SMA filtration

Figure 7
Visual interpretation of filtered and unfiltered randomly generated data: WMA filtration



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Figure 8

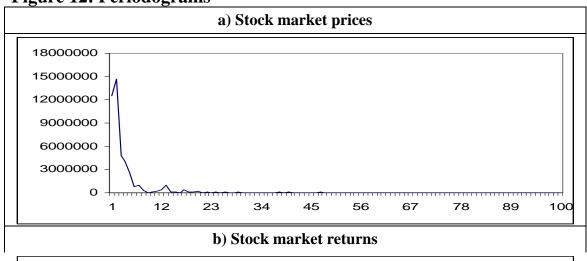
Visual interpretation of filtered and unfiltered randomly generated data: Irwin filtration

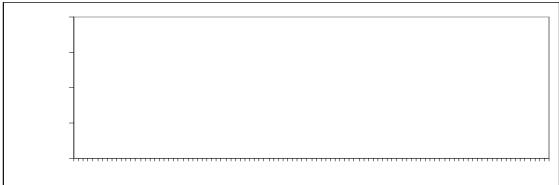
Figure 9: Dynamics of Hurst exponent during 2003-2013

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a) Stock market prices







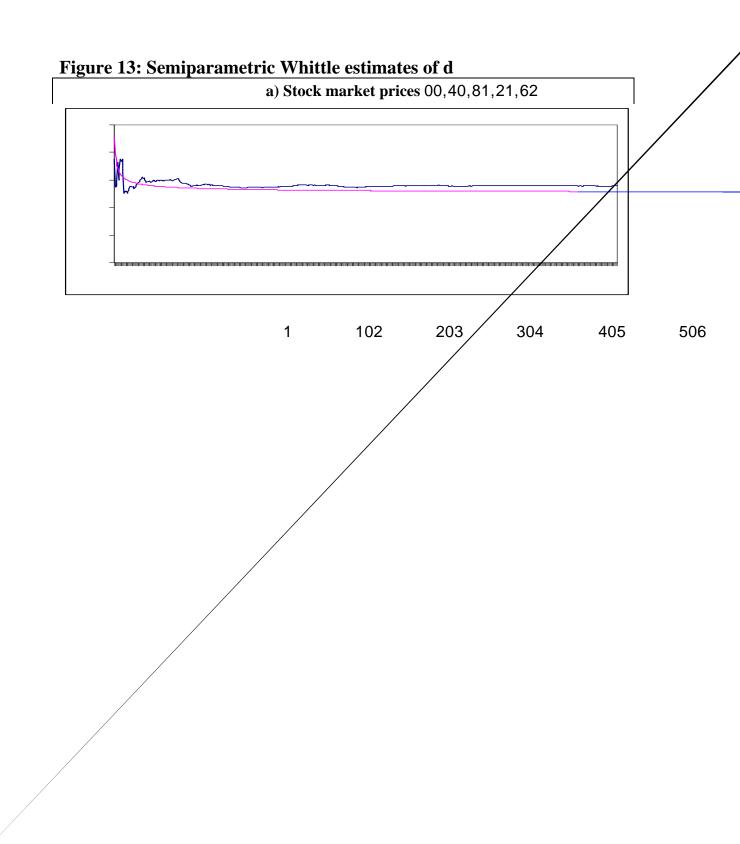


Figure 14: Stability results based on recursive estimates

a) Stock market prices

Adding 10 observation each time Moving windows of 300 observations