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Long-Range Dependence in Exchange Rates: the case of the European Monetary System

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Abstract

In this work we measure the evolution of the long-range dependence phenomenon of returns and volatilities of nominal British exchange rates (British pound against US dollar) futures contracts negotiated on the Chicago Mercantile Exchange from 1986 to 2004. The measurement employs the R/S classic analysis, Detrended Fluctuation Analysis and Generalized Hurst exponents, upon a 1008-observation window, which moves along the data. We obtain as a result, the effects of the 1992 European financial crises on the measurements of the long-range dependency phenomenon. After the crisis the returns of this futures contract showed no signs of the long-range memory, which existed before the crisis. The volatility presented moderate long-range memory the whole time. We also test for long-memory in European currencies inside the European Monetary System and find evidence of moderate long memory, which suggests that being inside the EMS increases predictability.

JEL Classification: G14; G15.

Keywords: long memory, exchange rates, R/S analysis, Financial crisis.

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1. Introduction

The possibility of predicting the behavior of asset prices is a subject that attracts the interest of most market agents because it facilitates the elaboration of strategies that may be used to gain profit by using appropriate positioning based on the behavior of predicted prices. The prediction of the behavior of asset prices is a complex problem and can be tackled in different ways. This complexity is derived from the fact that one cannot study, as an isolated factor, the effect of various factors that contribute to the formation of prices without losing a considerable part of the explicative power they possess. The approach using the prediction of price behavior in a market may be done from the viewpoint of process modeling, which requires data, which are frequently unavailable for the job, or from the viewpoint of studying the movement of prices in equilibrium. In this case, the factors that could be causing the movement are not modeled, but rather, various tests are made to identify the stylized types of processes that can cause the price movement observed.

Fama (1970,1991) related the study of the predictability of prices to informational efficiency, in weak form, of the market where it is studied. Within the categories of prediction of existing prices, this work will focus on predictability due to long-range memory. The study will be done for returns and volatilities of the first generic futures contract of the British pound negotiated in the Chicago Mercantile Exchange (CME) and on European currencies such as the Deutsche mark, French Franc and Italian Lira. The identification of long memory in the series of returns of these assets indicates the occurrence of inefficiency, in weak form, of that particular market. Since the efficiency of a market can be related to the immediate availability of information to all the participants of the market; to the speed with which this information is translated into attribution of asset value; and to market structure characteristics, it is only natural to expect that the efficiency of the markets be variable over time, reflecting the evolution of these factors. This is the case of Information Technology, whose evolution facilitated rapid transferal of information and the development of more sophisticated mathematical models for pricing assets.

The estimation of long-range memory in time series requires a great number of observations and is based on the supposition that the process being analyzed is stationary. It is probably for this reason that until now, most of the identification or estimation of long-range memory works is performed upon the whole data series, providing a single long range dependence parameter for the entire samples. The following authors, among others, carried out the identification or estimation of long-range memory: Crato and Ray (2000), Barkoulas et al. (1999), Fang, Lai and Lai (1994), Kao and Ma (1992) and Wang (2004). To the best of our knowledge no work have studied the evolution of long memory over time for futures markets. Furthermore, no single study has focused on currencies inside the European Monetary System (EMS) and tested whether being inside the EMS makes returns more predictable. We follow this path.

In the following study estimations are made regarding long-range memory variable in time, for returns and volatilities of the futures contract of British pounds negotiated in CME, and on Deutsche mark, Italian Lira and French Franc. We use the classic R/S analysis by Hurst (1951) and Mandelbrot (1972) and the Detrended Fluctuation Analysis (Moreira et al. (1994) and Peng et al. (1994)) and Generalized Hurst Exponents (Barabasi and Vicsek (1991)). We also employ time-varying estimation to test whether the British pound crisis and the drop out of the British from the EMS has provoked any structural breaks in the long memory parameters. The measurements of long-range memory obtained over time are analyzed and compared to investigate the characteristics of the generating processes that could be possible long memory causers. At the end we present the tendency observed in the evolution of long memory of returns, for the analyzed futures contract.

The remainder of this paper is structured the following way. In the next section a brief theoretical review is introduced. In section 3 we present the methodology considered in this work. In section 4 the data is presented, the way it is prepared for the calculations and the context in which it is applied. In section 5 the empirical results are shown. Section 6 concludes the paper.

2. Long memory estimation

A series of observations shows long memory when the values observed in distant lags are co-related among themselves or if the effect of an event, which occurs in an instant can be detected many lags afterwards. Specifically, one can say that a series of observations, stationary in covariance, has long memory if its function of auto-covariance is not summable.

Let X_t be the return of a time series at instant t. Long memory is typically characterized by the hyperbolical decay of the auto-covariance function, defined by γ_k = Cov (X_k; X_0). This decay has a rate k^{2d-1}, with $0 < d < 0.5$. When long memory occurs, we have $\sum_{j=-\infty}^{\infty}|\gamma_j| = \infty$. In the case of short memory, the auto-covariance function decays geometrically, tending to zero rapidly. Therefore, when there is short memory, the sum of the autocovariances has finite value.

If no long memory is detected in a series of observations, this indicates that:

i) There is no dynamic process involving the variable observed and other factors.

ii) There is a dynamic process with short memory, which may have complicated dynamics.

iii) The dynamic process exists, but the memory is too short for the effects of the state of the system in one instant to last until the next, established according to the rate of the observation sample. As there might have been some variation (shock) in the exogenous variable of the system and as the reaction of the system as well as the dissipation of the effects are very rapid, the state of the system in one instant will not maintain a relationship with the state in the prior instant. As a consequence the values registered in the time series under study will not maintain a relationship among themselves. In practice, this amounts to the Brownian movement[1].

The evaluation of long memory of a series can be done by diverse methodologies. Among the methodologies used today in the identification and quantification of long memory, the most popular ones are the R/S classic analysis, developed by Hurst (1951) and Mandelbrot (1972), the modified R/S analysis, by Lo (1991), the estimation of the parameter of fractionary integration by spectral regression, or log-periodogram, by Geweke and Porter-Hudak (1983), the log-periodgram semi-parametric estimator by Robinson (1995) and the V/S

[1] Robert Brown first observed the Brownian movement in 1828. He verified that the random movement of microscopic pollen did not have biological causes, as was supposed, but rather, physical causes which were a result of the movement of microscopic particles colliding into each other, driven by thermal energy. The Brownian movement, observed under a microscope, consists of displacements in random directions and length, which can be described by characteristic value. The term “random walk ” is used in the Brownian movement context. See Feder (1988).

analysis, by Giraitis et al. (2003). These methodologies can be used without knowing the factors which act in the price-generating process, taking into account only the series of returns or volatilities (or residuals of these variables in relation to regressors) for those where long memory estimations are desired. In general, these methodologies result in long memory parameters, be they the exponent of Hurst "H", or the parameter of fractionary integration "d", which can be used in the econometric modeling of processes with average long memory, such as ARFIMA (k, d, l) (*Auto Regressive Fractionally Integrated Moving Average*), proposed by Granger and Joyeux (1980) and Hosking (1981).

Hurst (1951) formulated the R/S analysis and derived the empirical relation which provided what is now called the Hurst exponent. Later, Mandelbrot and Wallis (1969) and Mandelbrot (1972) and (1975) did studies to evaluate the confidence of the R/S statistic as an identifier of predictability due to long memory. Mandelbrot (1971) also considered the existence of long memory in financial assets. Wallis and Matalas (1970) affirmed that short-term autocorrelations could affect the value of the calculated Hurst exponent. Having this limitation of the R/S statistic in mind, Lo (1991) formulated the modified R/S statistic to avoid sensibility of the R/S statistic to short-term co-relations. Teverovsky et al. (1999) later verified that the modified R/S analysis was conservative in relation to the rejection of the null hypothesis, which says there is no long memory.

Regarding futures of British pound against the US dollar a few studies have suggested that these contracts do not possess long-range dependence in mean but present evidence for volatility[2]. Furthermore, we test whether currencies inside the EMS are predictable and compare the degree of predictability of the British pound before and after leaving the EMS. It is worth mentioning that time-varying Hurst exponents are indicative of multifractality for time series.

The contribution of this paper is to develop a statistical procedure to test for long-range dependence and evaluate changes in the degree of long-range dependence over time, which is evidence of multifractality. Calvet and Fisher (2001) explore the implications of multifractality and suggest a new modeling procedure that can be seen as a competitor for ARCH/GARCH models. The authors found evidence of multifractality for a variety of stock indices and exchange rates.[3]

3. Methodology

3.1 Hurst exponent evaluation

The analysis of the R/S statistic was formulated by Hurst (1951) when he was studying problems of dam dimensioning which sought to determine the ideal capacity of the dam, given the data of the annual water flow associated to the same over the period of a few decades. The idea consisted of determining which were the maximum and minimum volumes in the reservoir, because overflow and dry-up were to be avoided. The difference between maximum and minimum volume equaled the volume range of the reservoir. Besides this, the standard deviation of the water flow was calculated, and the R/S statistic would be the result of the division of the range by the standard deviation, which is a dimensionless value. Hurst, upon analyzing this statistic, for diverse time periods of this series of observations, discovered that there was a function related to the value of the R/S statistic to the number of observations, which entered the calculation. Later he verified that this relation was also valid for other

[2] See Kao and Ma (1992), Fang et al. (1994), Barkoulas et al. (1999) and Crato and Ray (2000).

[3] See also Sun et al. (2001), Xu and Gencay (2003) and Wei and Huang (2005).

natural phenomena. In this relation the R/S statistic is equal to half the number of observations taken to the "H" exponent, later known as the Hurst Exponent.

Later still, Mandelbrot and Wallis (1969) and Mandelbrot (1982) verified that the empirical relation discovered by Hurst showed the same form presented by the series that describe the fractionary Brownian movement, namely the rescaled range (R/S) as a function of the period utilized in the calculation (τ) and thus, the Hurst formula was applicable to processes described by the fractionary Brownian movement. This means that the R/S statistic and Hurst exponent "H" can be used to represent the long memory properties of the fractionary Brownian movement. Thus, the values of Hurst exponent obtained in this manner have the following interpretation: $0 < H < 0{,}5$: anti-persistent series; $H = 0{,}5$: series presents *random walk*; $0{,}5 < H < 1$: persistent series.

The Hurst exponent may be calculated as follows. Let X(t) be the closing price of a futures contract and r(t) the logarithmic return of this contract on this date, given as :

$$r_t = \ln (X_t) / X_{t-1}) \ . \tag{1}$$

To estimate the long memory of a series of volatilities, the absolute value r_t. is used as an approximation for instant volatility.

The total number of returns for the series is N. To calculate Hurst exponent "H", various calculations of the R/S statistic for blocks of τ observations are made, being that $\tau \leq N$. For each vale of τ, the R/S statistic is calculated in this manner:

i) The N returns series is divided into n contiguous of τ elements, numerated with $1 \leq i \leq n$. In each block i, the elements r_{t},i are numerated with $1 \leq t \leq \tau$.

ii) The R/S statistic associated to the size of block τ is calculated,

iii) The average returns of each block is given by

$$\bar{r}_i = \frac{1}{\tau} \sum_{t=1}^{\tau} r_{t,i} \ . \tag{2}$$

The standard deviation in each block is calculated as

$$S_i = \left[\frac{1}{\tau} \sum_{t=1}^{\tau} \left(r_{t,i} - \bar{r}_i \right)^2 \right]^{1/2} \ . \tag{3}$$

For each block i, the statistic $(R/S)_i$ is calculated using

$$(R/S)_i = \frac{1}{S_i} \left[\max_{1 \leq t \leq \tau} \sum_{k=1}^{t} \left(r_{k,i} - \bar{r}_i \right) - \min_{1 \leq t \leq \tau} \sum_{k=1}^{t} \left(r_{k,i} - \bar{r}_i \right) \right] . \tag{4}$$

The average of the values $(R/S)_i$, associated to the size of the block τ is then evaluated

$$(R/S)_\tau = \frac{1}{n} \sum_{i=1}^{n} (R/S)_i \ . \tag{5}$$

iv) Having terminated the calculations of the R/S statistic for various values of the length of block τ, one finds Hurst exponent "H" from the relation

$$(R/S)_\tau = (\tau / 2)^H \tag{6}$$

Given the pairs $(R/S)_\tau$ and τ, obtained in ii), the regression is made, according to Mandelbrot and Wallis (1969):

$$\ln(\text{R/S})_\tau = \ln \text{C} \;+\; \text{H} \ln \tau \;+\; e \tag{7}$$

where *e* stands for the residual of the regression.

3.2 Evaluation of the R/S analysis as a method of estimating long memory

Among the strong points favoring the use of the R/S statistic to estimate long memory are the superiority of this method compared to the more conventional ones, like the autocorrelation analysis, variance ratio and spectral decompositions, according to Lo (1991). The R/S statistic can identify long memory in temporal series, which are very far from normality, with great asymmetry and kurtosis, according to Mandelbrot (1969). Mandelbrot (1972, 1975) also report almost sure convergence of the R/S statistic for stochastic processes with infinite variance, and evident advantage over autocorrelations and variance ratios. Besides this, Mandelbrot (1972) states that, contrary to spectral analysis, the R/S analysis can detect non-periodical cycles and cycles having a period which is equal or greater than the sample period. Lo (1991) affirms that, despite the fact that these strong points be, up to a certain point, argumentably, the R/S classic statistic can, recognizably, identify long memory.

A weakness of the R/S method is that it also detects short memory, without differing it from long memory. Lo (1991) proposed a modified R/S statistic to solve this problem. However, Teverovsky et al. (1999) and Taqqu et al. (1999) evaluated the modified R/S analysis proposed by Lo to test the possibility of predictability due to a long memory in a Monte Carlo experiment. They concluded that although the modified R/S analysis represented an improvement of the R/S classic analysis, there was still one limitation: it was conservative in relation to the rejection of the null hypothesis, which says that there is no predictability because of long memory. In other words, if Lo's method indicates that there is no evidence of predictability due to long memory, the investigation must continue. Therefore, they recommend that this method of analysis be employed along with other tools for the verification of this type of predictability.

To avoid the sensitivity of the R/S analysis to short-term autocorrelations one could use:

i) Subdivide the series in non-overlapping blocks of 5, 10 or 20 observations and shuffle each block randomly, with the goal of destroying the structure of auto co-relations within these blocks. This was done for the first time, within the context of identifying long memory, by Erramilli et al. (1996).

ii) Aggregate the data of the non-overlapping blocks of the series and submit the result of this aggregation to R/S classic analysis. In this case, the series to be analyzed is divided into blocks of 5 and the average of each block is calculated, which makes the series closer to normality.

In this work the methodology of shuffling series data is used because it is not based on restrictive hypotheses regarding volatility (GARCH filter), neither does it reduce the number of observations to be informed for the R/S analysis. One last consideration regarding the evaluation of the classic R/S analysis as a method of estimating long memory is the subject of uncertainties, which involve the calculation of the value of Hurst exponent.

In the first place, calculating Hurst exponent by way of the R/S classic analysis is asymptotic, which results in error, which will be greater the smaller the sample submitted to analysis is. The R/S classic analysis does not predict correction for the R/S statistic in the case of small samples. To deal with this need, Couillard and Davison (2004) proposed correction for Hurst exponent calculated by the R/S statistic, taking the size of the sample into account. They also defined a calculation for the standard deviation of Hurst exponent calculated by this new method. This work does not use this correction but seeks to consider the possibility of the occurrence of this type of distortion in the analyses. Besides this, the R/S classic statistic has no known distribution under the null hypothesis of having no long memory, according to Crato and Ray (2000).

3.3 Long memory estimation using GH and DFA methodologies

Following Taqqu et al. (1995), which suggest the use of a "portfolio" of long-range dependence estimators, it is also employed two other methods to estimate Hurst exponents, namely the generalized Hurst exponent (GH) and Detrended Fluctuation analysis (DFA).

The generalized Hurst exponent is used to calculate the Hurst exponents (H) in the following way. Let Y(t) be the integrated time series of logarithm returns, i.e., Y(t)=log(X(t)). The generalized Hurst exponent is a generalization of the approach proposed by Hurst. Barabasi and Vicsek (1991) suggest analyzing the q-order moments of the distribution of increments, which seems to be a good characterization of the statistical evolution of a stochastic variable Y(t).

$$K_q(\tau) = \frac{\left\langle \left| Y(t+\tau) - Y(t) \right|^q \right\rangle}{\left\langle \left| Y(t) \right|^q \right\rangle} \quad . \qquad (8),$$

The detrended fluctuation analysis (DFA) is performed in the following way (Peng et al. (1994)). Let Y(t) be the integrated time series of logarithm returns, i.e., Y(t) = log(X(t)). In this method one considers the τ-neighborhood around each point Y(t) of the time series. The local trend in each τ-size box is approximated by a polynomial of order m, namely Z(t). Then, one evaluates the local roughness

$$\varpi^2(Y,\tau) = \frac{1}{\tau} \sum_{t \in \upsilon} (Y(t) - Z(t))^2 \ . \qquad (9)$$

Moreira et al. (1994) showed that the following scaling relationship holds

$$\left\langle \omega^2(\tau) \right\rangle \sim \tau^{2H} \ , \qquad (10)$$

where H is the Hurst exponent.

4. Data

This work is based on two data sets: the closing prices of the 1st generic British pounds futures contract[4], denominated in U.S. dollars and negotiated on the Chicago Mercantile Exchange (CME) and the spot British pound exchange rate, expressed in U.S. dollars. These series of data were obtained from Bloomberg.

In a generic futures' contract series, the substitution of a price series by the price series, which will expire next may potentially provoke an impact in the long memory calculations being made. For this reason we filter the returns series using a regression with a dummy for the introduction of the new contract. The process for filtering the generic contract series uses the model $r_t = X\beta + \varepsilon$, where:

i) $r_t = \log(P_t/P_{t-1})$, being P_t the price on day t

ii) Two columns form the X matrix. There is one for the intercept and another for the dummy used for the rollover dates (i.e., the maturity dates). This dummy has value one for 't' being the following day of a futures contract maturity date, and zero otherwise.

iii) For filtering the series, the regression is performed and the residuals are taken as the series to be analyzed.

We then compare results obtained by testing for long-range dependence in the original returns series and the filtered return series (residual of the regression described above).

The spot exchange rate series does not go through this process. The table below shows a summary of the data of the analyzed priced series.

Table 1 – Series of exchange rates – closing daily observations.

	Serie	Currency	Country	Rollover	Data from/to		Obs
BP1	1st generic contract GBP/USD	USD	USA	3 mths	27-May-1986	06-Oct-2004	4633
GBP	Exchange Rate GBP/USD	USD	USA	–	27-May-1986	06-Oct-2004	4633

Where BP1 is the 3-months futures contract for the GBP (Great Britain pound exchange rate).

From the price series shown above, the returns series $r_t = \ln(X_t/X_{t-1})$ are obtained, X_t and X_{t-1} being the closing prices on dates t and t-1, and volatilities v_t = absolute value r_t, which will be analyzed. Due to the fact that short-term autocorrelations could affect the value of Hurst exponent to be calculated using the R/S classic analysis, a data shuffling is made of the returns samples and volatilities to be studied, within contiguous blocks of 20 observations before doing the calculations, with the goal of destroying the short-term autocorrelations, which possibly exist.

Initially, the authors sought to estimate the impact of shuffling data in the results to be obtained. 100 calculations of Hurst exponents were performed for the futures contract returns series to be studied. In each calculation, the series data were re-shuffled in the same way proposed in this paper. After this, the Figures of the Hurst exponent over time were plotted for

[4] A 1st generic contract series is formed by the next maturing futures contract series in a given time interval. In fact, the series we analyzed were formed by the daily closing prices of the closest to the next maturity contracts from May 86 thru Oct 06. The real futures' contracts mature quarterly, on the third Wednesday on March, June, September and December. On the day following the maturity date of a contract, the closing prices used to form the generic contract series begin to be got from the next maturing contract series. The use of generic futures contract series is justified by the need of analyzing data periods longer than the period during which the 'real' currency futures contracts are negotiated and liquid. This procedure was carried, for instance, in Barkoulas et al. (1999), Fang et al. (1994), and Crato and Ray (2000).

each calculation and compared to the interval of 95% confidence obtained for the series of Hurst exponents throughout time, calculated from a specific shuffling of the series, chosen at random. As can be seen in Figure 1 below, in most of the calculations done over time, the envelope of the Hurst exponents calculated for the 100 shufflings is external to the confidence interval obtained for a given shuffling, which shows the impact that a sample shuffling could cause to the results.

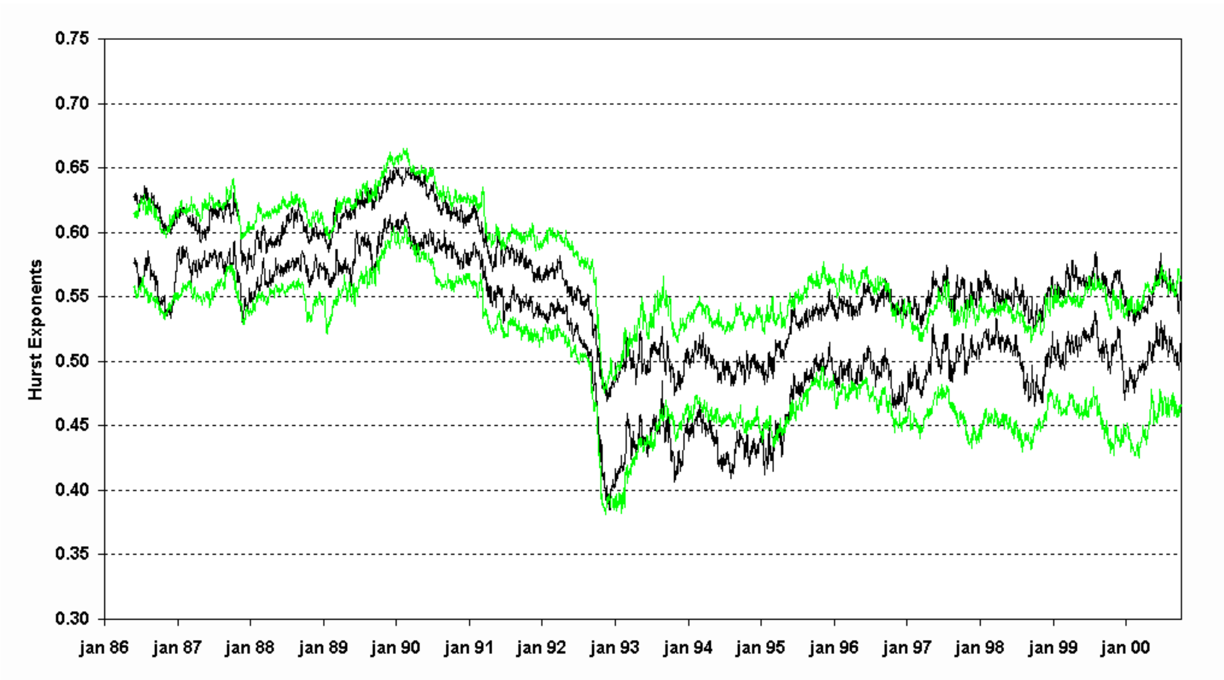

Fig. 1. Comparison between the envelopes of Hurst exponents curves calculated for 100 different shufflings and the confidence interval of 95% of the Hurst exponent calculated for 1 shuffling chosen at random (darker color).

The median of the H values calculated for these shufflings varied between 0.496 and 0.545; the median of the H values for the unshuffled sample was 0.540, while the median of the H values for the returns sample that suffered the specific shuffling cited above was 0.536. The Hurst exponents calculated over time for the unshuffled returns sample stayed outside the envelope of the Hurst exponents calculated for the 100 shufflings in 2.4% of the times, and stayed outside the confidence interval of 95% of Hurst exponents calculated for the shuffling sample cited above 12.6% of the time. A solution to this problem would be the construction of a curve with the median of Hurst exponents calculated from 100 shufflings for each date. This could be done for the average value and for the confidence intervals, but it is a costly computational procedure. Another possibility would be to filter the series with the goal of removing the short-term autocorrelations. In this work it was decided to use the shuffling of data chosen at random, cited above, taking into account the imprecision that this can bring for the estimations of long term evolution over time. However, to avoid distortions of the comparisons between series of the spot market data and futures markets, and between series of unfiltered futures markets and those filtered taking into account the maturities' dates, the same shuffling was used in all the calculations, for the returns series as well as for the volatilities[5].

Lastly, and briefly, the context from which these data were extracted will be presented. They focus on the pre crises period of 1992 and are based on the work of Eichengreen and Wyplosz (1993). The period of the sample studied was from May 1986 to October 2004. In the initial part of the sample Great Britain belonged to the European Monetary System (EMS). With the occurrence of the financial crisis of September, 1992, Great Britain left this system and continues that way until this day.

The EMS was constituted in 1979 by 11 countries, which formally linked their exchange rates through the Exchange Rate Mechanism (ERM). During the period that terminated in January, 1987, the exchange rates of the countries which participated in the EMS were connected among themselves by the establishment of bands in which they had to stay. Nevertheless, from time to time it was necessary to realign the exchange rates because of the persistency of inflation differentials among these countries. From 1979 to 1983 these inflation differentials were significant, beginning to fall only after 1987. From January, 1987 until the crises of 1992, no other realignment occurred, due to the fact that the formulators of monetary policies began to believe that the inflation differentials were not due to imbalances within the EMS, but to the declining dollar and expectations of self-made speculation.

This interpretation resulted in the revision of projected procedures to strengthen the intervention capacity of the countries and to encourage the coordination of monetary polices so that speculative attacks would not destroy exchange rate stability sought by the EMS. Despite the restrictions imposed during the process of European monetary unification, after 1987, the countries still had autonomy for limited periods.

In July of 1990, the Single European Act recommended the abolition of the controls on the flow of foreign capital in the EMS countries. Most of the countries removed these controls during the first semester of 1990. From 1991 on, the EMS situation could be characterized by the presence of inflation differentials among the countries, along with the absence of the realignment of exchange rates and controls on capitals flows. In this context, in 1992, symptoms of instability began to emerge. Initially, the Italian lira fell below the limits of the exchange band established for it and later the same occurred to the British pound. In August, Great Britain spent at least $1.3 billion of its reserves to finance exchange rate interventions. On 16 September, the Bank of England announced it had spent $20 billion on interventions, an amount that was equal to half of the international reserves.

The country also elevated its discount rate to 15%. These measures did not work and Great Britain had to take its British pound out of the ERM. After this, the British discount rate was reduced to half and the exchange began to float freely. After leaving EMS, Great Britain could no longer return, due to a condition of the Maastricht treatise, concluded on 7 February, 1992 which stated that if a country should leave the EMS, it could no longer return to the qualification process to become a member of the European Monetary Union and thus would have no motivation to submit to the necessary austerity policies to conclude the unification process. This fact caused a structural change in the exchange regime of Great Britain, starting when Great Britain left the EMS. The effects of this on futures contract returns of the futures contracts of the British pound shall be studied now.

We also study the long-range dependence properties of the Italian Lira, Deutsche mark and the French Franc to infer whether being inside the EMS would render returns more

[5] It is important to notice though that qualitative results are similar. They are not reported in this paper to conserve space.

predictable. These currencies were selected due to its availability for a long time span (which would render the long-range dependence estimation reliable).

5. Empirical results

Hurst exponents were calculated over time, using the classical R/S analysis, for returns and volatilities of the British pound futures contract with and without filtering for rolling maturities. They were also calculated for returns and volatilities of exchange rates in the spot market in order to investigate the relation that exists between long memory estimated for the asset in the spot market and the long memory estimated for the asset in the futures market, considering that the price of the futures contract is formed from the price of the asset on the spot market. In all the calculations the samples were shuffled in the same manner to avoid distortions in the comparative results due to the use of different observations shufflings.

Filtering was not performed for days of the week because sample shuffling in 20-observation blocks destroys the dependencies regarding days of the week that could exist. In table 2 we present the statistical characterization of Hurst exponent series calculated over time.

Table 2. Descriptive Statistics for Time-Varying Hurst exponents calculated for the returns' and volatilities' series (R/S Methodology).

	Returns			**Volatilities**		
	BP1 Not Filtered	BP1 Filtered	GBP	BP1 Not Filtered	BP1 Filtered	GBP
Mean	0.5395	0.5404	0.5440	0.7001	0.7013	0.7016
Median	0.5327	0.5362	0.5280	0.7066	0.7073	0.7097
Maximum	0.6298	0.6328	0.6385	0.7729	0.7760	0.7690
Minimum	0.4273	0.4291	0.4391	0.5716	0.5718	0.5816
Std. Dev.	0.0463	0.0482	0.0469	0.0458	0.0464	0.0424
Skewness	-0.0831	-0.1491	0.2355	-0.4150	-0.4110	-0.6268
Kurtosis	2.0605	2.0835	1.8007	2.0983	2.0927	2.3969
Jarque-Bera	137.5	140.3	250.8	226.8	226.4	292.3
P-value	0.0	0.0	0.0	0.0	0.0	0.0
Observations	3625	3625	3625	3625	3625	3625

BP1 stands for British Pound 3-months futures contract, traded on the Chicago Mercantile Exchange.
GBP is the spot British pound exchange rate. The filtering made for the BP1 is regarding to maturities' dates.

The Hurst exponents were also calculated by the Generalized Hurst and DFA methodologies, for returns and volatilities of the British pound futures contract, yielding the results presented in Table 3:

Table 3. Descriptive Statistics for Time-Varying Hurst exponents calculated for the returns' and volatilities' series (GH and DFA Methodologies).

	Returns BP1		Volatilities BP1	
	GH	DFA	GH	DFA
Mean	0.5079	0.4971	1.0008	0.6766
Median	0.5023	0.4771	1.0009	0.6804
Maximum	0.5522	0.5957	1.0047	0.7741
Minimum	0.4447	0.3878	0.9932	0.5492
Std. Dev.	0.0241	0.0537	0.0017	0.0562
Skewness	-0.1959	0.1577	-0.5563	-0.3832
Kurtosis	2.4713	1.6734	3.8743	2.1182
Jarque-Bera	65.4	280.9	302.5	206.2
P-value	0.0000	0.0000	0.0000	0.0000
Observations	3625	3625	3625	3625

BP1 stands for British Pound 3-months futures contract, traded on the Chicago Mercantile Exchange, filtered for maturities' dates.

The value obtained for the Jarque-Bera statistic permits the rejection of the null hypothesis of normality of the Hurst exponent series over time. Figure 2 presents the evolution of the Hurst exponent for the British pound.

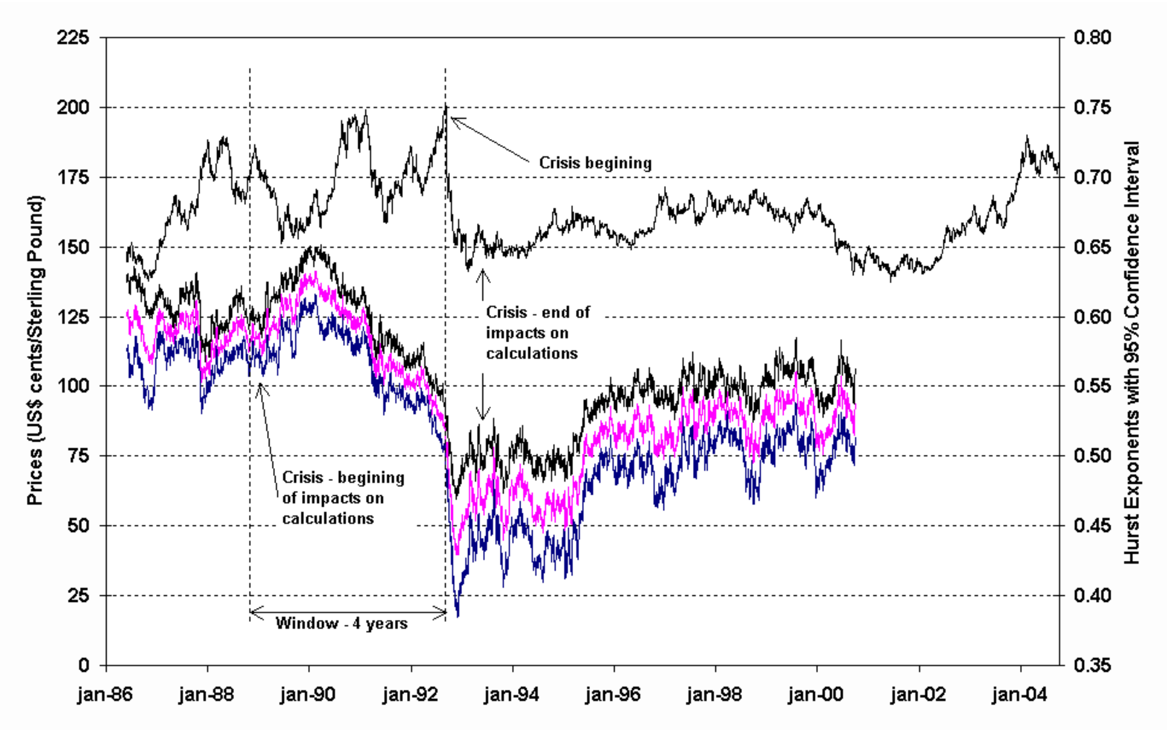

Fig.2 Impact of the EMS crisis on the Hurst exponents over time for the returns of the next 3-month British pound futures contract series, filtered for maturities' dates. The futures contract prices are also show.

The Kernel density of the Hurst exponent over time series (R/S analysis), calculated for the British Pound futures contract (returns) is bi-modal (see Figure 3), which can be partially explained by the structural break occurred.

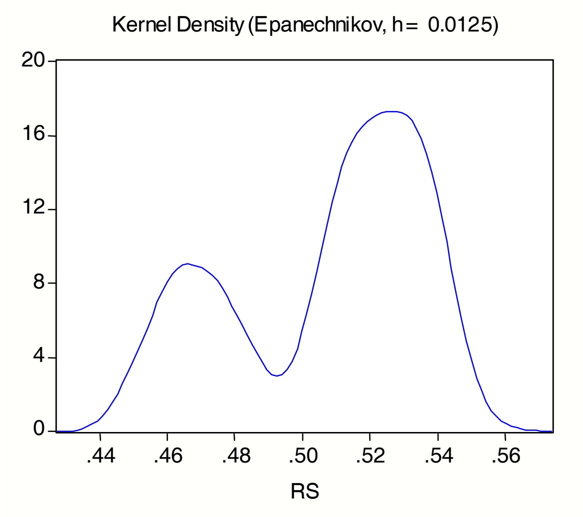

Fig.3 Kernel density of the Hurst exponent over time series (R/S analysis), calculated for the British Pound futures contract (returns)

In order to assess whether the Hurst exponents are varying over time after the 1992 crisis, it was employed two different approaches. In the first one, the Hurst exponents where estimated for different time periods of approximately 6 years: the first ended immediately before the crisis, the second began 2 months after the crisis, in the end of 1992, and the last began in 1998. The standard errors for these Hurst exponents, which were used to test whether these exponents were different within different time periods were estimated through a post-blackening bootstrap approach. The following steps give this procedure:

i) The Hurst exponent for the original series is estimated, obtaining "H".

ii) The pre-whitening of the series is made, estimating an AR(p) model with p sufficiently high. The order of the auto-regressive model is estimated through the Akaike information criteria. The residuals (e_t) of the model and the centered residuals $e_t - \bar{e}_t$ are obtained. In our case we employ p = 30.

iii) A new series of innovations through the bootstrap of moving blocks (MBB)[6] is generated. In this process, a block length of the block = 5 observations is used, according to the Hall *et al.* (1995) rule.

iv) The post-blackening is made, adding the innovations series generated by bootstrap to the model whose parameters were generated in the pre-whitening, to obtain the synthetic series.

v) For each synthetic series, the Hurst exponent H_b is estimated.

vi) At the end of the process, the Wald statistic is calculated given by:

[6] This technique was studied by Kunsch (1989) and consists of the division of the original series in blocks of the same length, which are picked out with reposition and juxtaposed, in order to form a new series of the blocks that were picked out, with the same length as the original series. Kunsch also studied the bootstrap of blocks of blocks, which consists of selecting randomly blocks formed in order to preserve the statistical structure of the original series.

vii) $W = \frac{(H - 0.5)^2}{(S(H_b))^2}$, $S(H_b)$ being the standard error of the Hurst exponents obtained through the bootstrap, and 0.5 the null to be tested. The Wald statistic is distributed as a chi-square with 1 degree of freedom, with 3.8 and 6.6 as initial values at the 5% and 1% levels, respectively.

The results of these calculations are shown in Table 4, employing the R/S, GH and DFA methodologies.

Table 4. Hurst exponents for the British pound futures contract in different time periods

	Returns		
Period	**1**	**2**	**3**
Sample Begins	5/27/1986	11/16/1992	1/7/1998
Sample Ends	9/14/1992	3/9/1999	10/6/2004
Num. Obs	1586	1586	1444
R/S - H	**0.6021**	**0.4640**	**0.5259**
std. Error	0.0321	0.0330	0.0360
Wald	10.1469	1.1913	0.5158
GH - H	**0.5273**	**0.4679**	**0.5158**
std. Error	0.0098	0.0100	0.0097
Wald	7.7590	10.3480	2.6322
DFA - H	**0.5726**	**0.4384**	**0.4771**
std. Error	0.0072	0.0072	0.0070
Wald	101.1659	73.8842	10.8126

DEM, DM1, FRF, GBP and ITL stand for spot Deutsche mark, DM1 for the three-month futures contract on Deutsche mark, FRF for the spot French Franc, GBP for the spot British pound and ITL for the spot Italian Lira. Hurst exponents for each method, R/S, GH and DFA, are presented in bold.

We employ a Wald test for structural change in Hurst exponents for periods 1 and 2. For all tests we reject the null that there is no structural break (Wald tests are 8.9, 17.9 and 173.7 for the R/S, GH and DFA, respectively). An important feature of these estimators is that the R/S seems biased with high standard errors, while the DFA seems to be the most precise estimator. When we test for a structural break for the first and third periods we reject the null of no structural change only with the DFA methodology. These results suggest that the 1992 crisis has provoked the major structural change in Hurst exponents.

After having identified that the Hurst exponents had different values in the 2 time periods after the crisis, for R/S, GH and DFA methodologies, it was estimated, for all methods, the trend in Hurst exponents after 1993, as shown in Table 5.

Table 5. Trend estimation for Hurst exponent evolution for the BP1 series, since 1993.

Methodology	Intercept	Trend	Adjusted R^2
R/S	0.4665*	0.0000416*	67.64%
	0.001989	0.00000171	
GH	-0.472958*	0.0000235*	53.54%
	0.001804	0.00000153	
DFA	0.437832*	0.0000175*	22.35%
	0.002755	0.00000213	

* Statistically Significant at the 1% level.
BP1 stands for British Pound 3-months futures contract, traded on the Chicago Mercantile Exchange, filtered for maturities' dates.

These results suggest that the trend is positive and significant. These results are robust for different specifications, including moving average terms in these regressions. Therefore, it suggests that Hurst exponents are increasing, although slightly, over time.

Figure 4 presents the evolution of Hurst exponent over time for the 3-month British pound futures contract, filtered for maturities' dates. Figures 5 and 6 show the same calculations using DFA methodology (Figure 5) and GH methodology (Figure 6). In Figure 7, it is presented the Hurst exponent over time for the volatilities of the time series, calculated through the R/S methodology. In these figures, the values of Hurst exponent attributed to a date represent the result of a calculation done for a data window which begins on that date, ends on a later date and contains 1008 observations (approximately 4 years of data), as shown in Figure 2.

Thus, the occurrence of an event causing structural change (as in the case of the European financial crises in September, 1992, which delimited two behavioral standards of futures contract prices studied), would cause a transition region in the Figure of Hurst exponents over time. Figure 2 shows this transition region. As the calculation window moves forward in time, the region where the crisis occurred and the post crisis behavior data enter the window, substituting the pre-crisis behavior data. The results obtained with the calculation window are attributed to the data at the left limit of the window. When the crisis data leave the calculation window there is an abrupt reduction of calculated values of Hurst exponent, because abrupt oscillations on the returns averages, which increase the calculated value of this exponent, are not in the sample anymore.

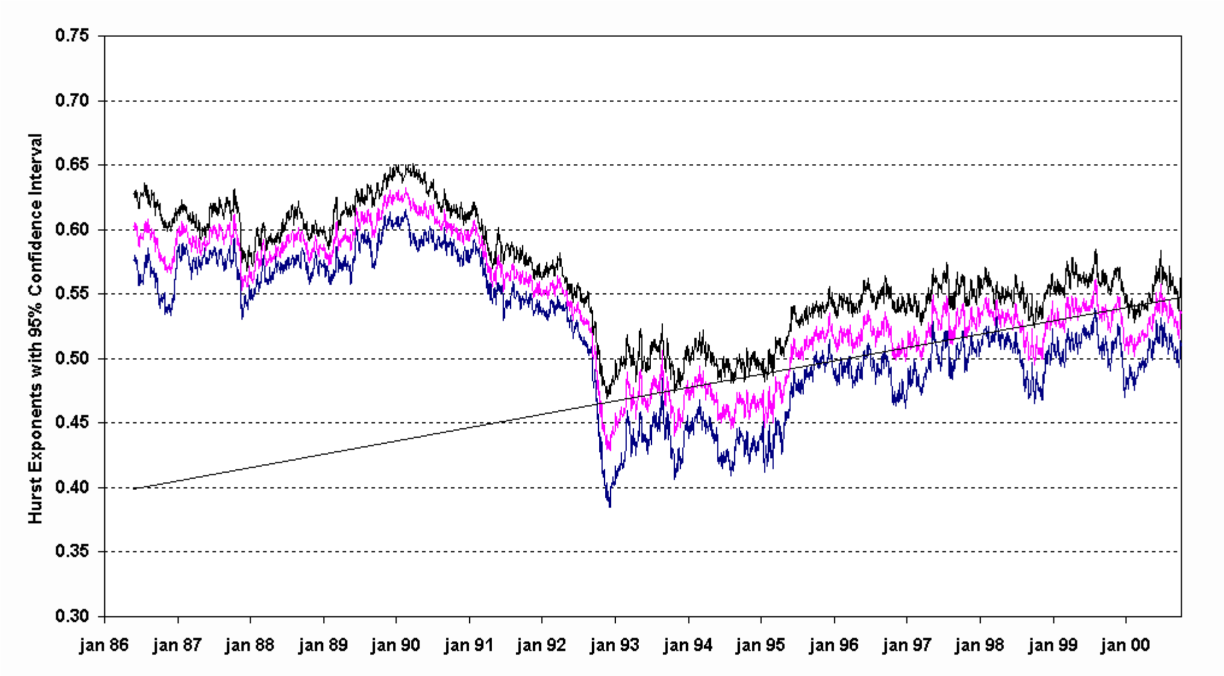

Fig.4 Hurst Exponents over time for the returns of the next 3-month British pound futures contract series, filtered for maturities' dates (R/S methodology). The Figure also shows the trend in Hurst exponents.

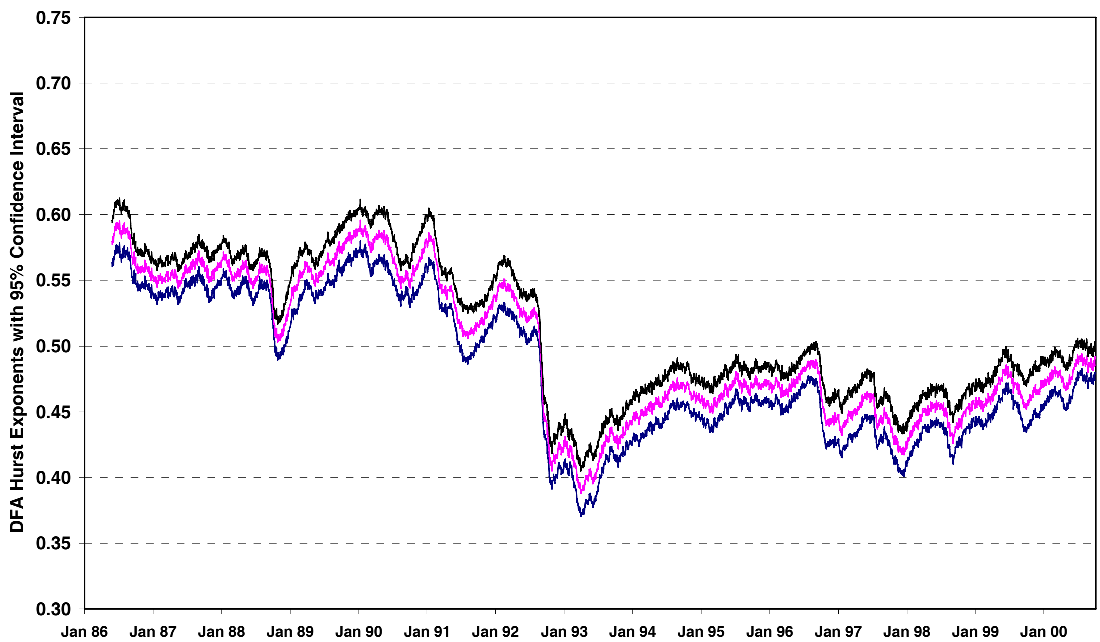

Fig.5 Hurst Exponents over time for the returns of the next 3-month British pound futures contract series, filtered for maturities' dates (DFA methodology).

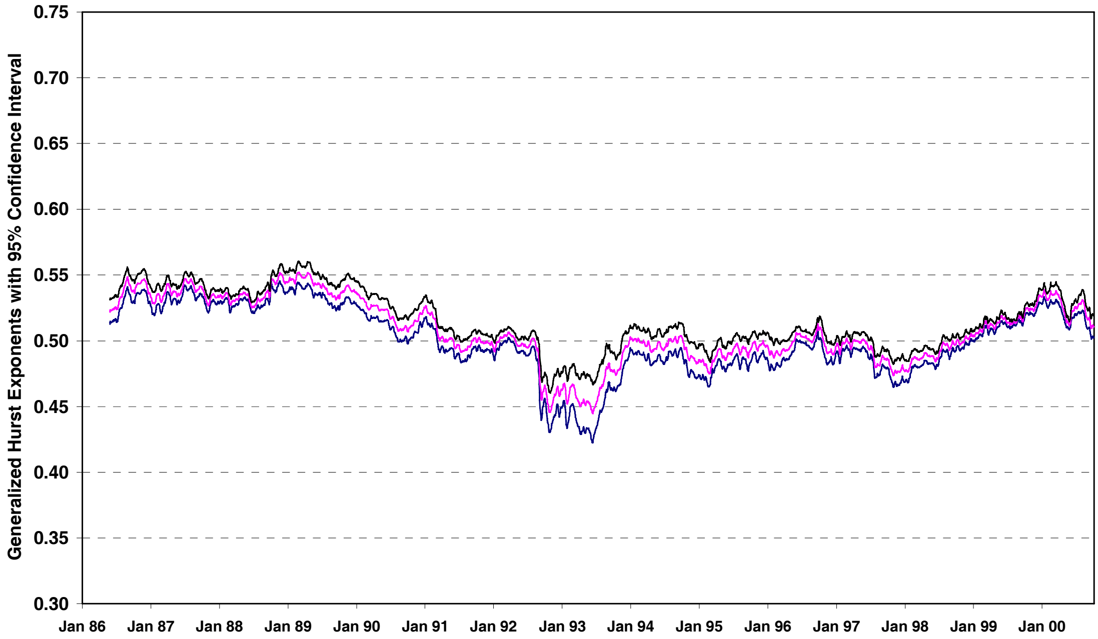

Fig.6 Hurst Exponents over time for the returns of the next 3-month British pound futures contract series, filtered for maturities' dates (GH methodology).

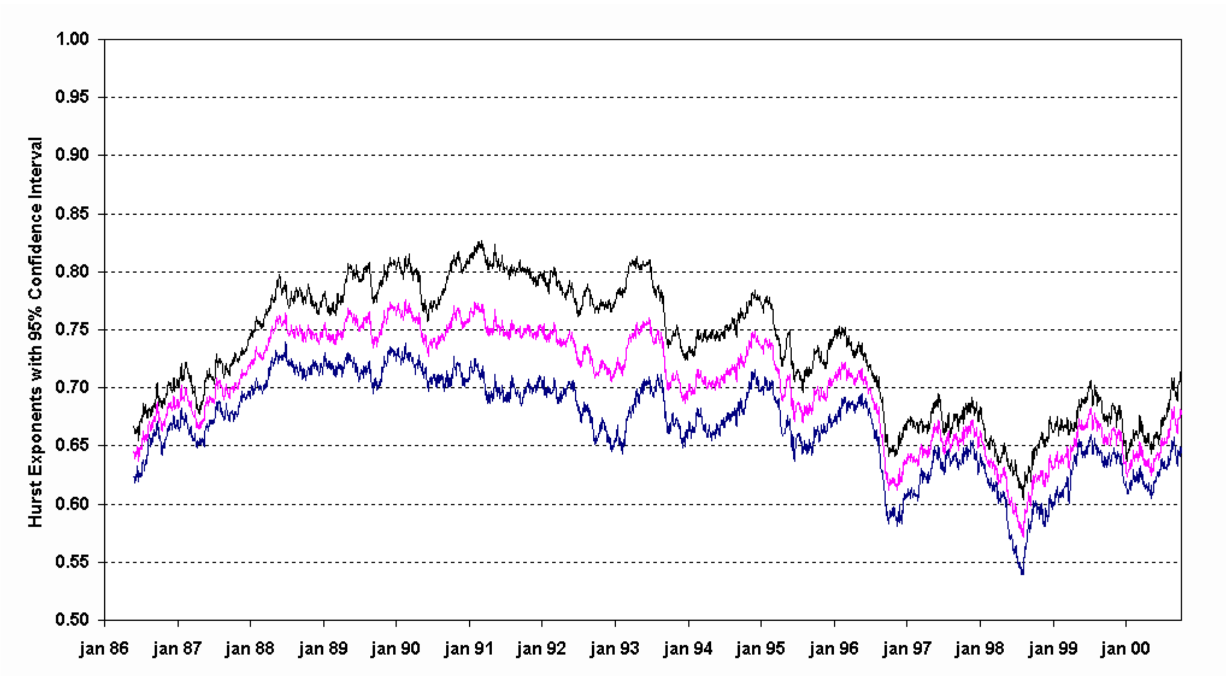

Fig.7 Hurst Exponents over time for the volatilities of the next 3-month British pound futures contract series, filtered for maturities' dates (R/S methodology).

The statistical description of the time-varying Hurst exponents calculated for returns' and volatilities' series of the British pound futures contracts, filtered and not filtered, and for the spot exchange rate of British pound against the U.S. dollar, show very similar figures for the R/S methodology (see table 2). Also, the plots of these Hurst exponents over time are very similar and can be fairly represented by the plots for the British pound futures contract, filtered, for returns (Figure 4), and for volatilities (Figure 7). These plots also allows us to conclude that long memory evolution, i.e., of Hurst exponents over time, for returns and volatilities of the filtered series of futures contracts, is strongly explained by the evolution of spot market prices, for this evolution produces a series of Hurst exponents very similar to that of the futures market.

Figure 4 shows a slower increase of Hurst exponents beginning in 1993, which corresponds to the period after the European crisis. The Figure also shows that during this period the British pound futures contract did not possess long memory. It was also calculated the trend of evolution of Hurst exponents over time for a single shuffling of the series of returns filtered by rolling maturities of the British pound futures contract, yielding an increasing of H at a rate per year of 0.0105 (R/S), 0.0059 (GH), and 0.0044 (DFA), as can be seen in Table 5. This trend was calculated from 1 April, 1993 when, after the end of the European financial crisis, it was established a new standard of evolution of Hurst exponents over time. This could be considered insignificant in face of the possibilities of macroeconomic alterations in 10 to 20 year horizons.

Finally, it was sought to interpret the results obtained for the series of futures contract returns, filtered by rolling maturities. To underpin this interpretation we used a Figure of log-returns of the British pound futures contract, which represents the series from which are calculated Hurst exponents of returns over time (See Figure 8).

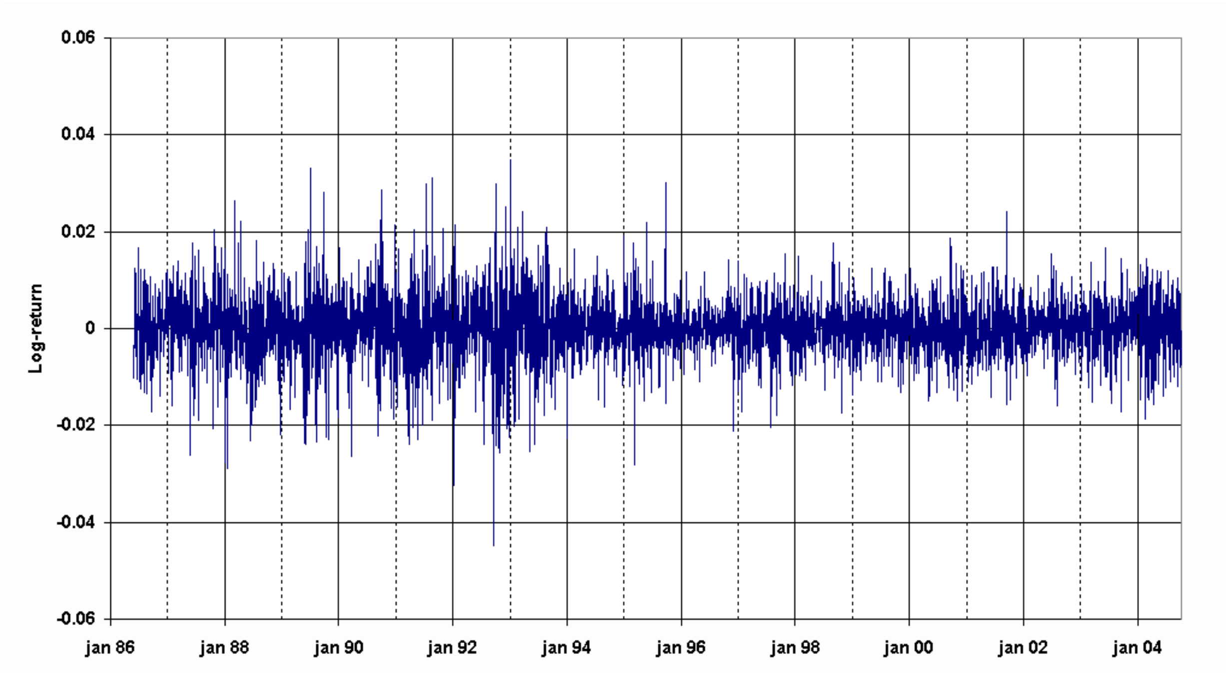

Fig. 8 – Log-returns of the next 3-month British pound futures contract

The changes observed between the pre crisis and post crisis regions in the sample are due to the exit of Great Britain from the European Monetary System (EMS), abandoning a band exchange regime in favor of a free-floating exchange rate regime. The behaviour of the British pound futures contract, expressed in dollars, in the sample period until the crisis, could be expressed as the composition of three processes: the process of floatation of the British pound in relation to the other currencies of the EMS, the process of floatation between the dollar and the currencies of the EMS, and the process of variation of the interest rates of the dollar and British pound, used to form the price of the futures contract from the price of assets in the spot market.

This last process has little impact on the performed measurements of long memory; the amount of long memory obtained results from the composition of the first two processes. Regarding the floatation of the British pound in relation to the other EMS currencies, the isolated fact that the Bank of England intervene in the exchange market to keep the exchange rates inside the band, does not affect the occurrence of long memory. It does affect, however, the manner of administrating the interventions and the results of these interventions, in terms of standards of rates floatation.

While administering the interventions, the monetary authority may try to revert the tendency of the exchange rate immediately or just try to soften the oscillations before the band limits are threatened; the choice of one of these alternatives produces different long memory measurements. The greater or lesser exchange band stability over time also produces impact on long memory. In regards to the post-crisis period, it can be seen that oscillations of the exchange rate between the pound and the dollar have less amplitude and greater irregularity. The Figure of prices shows greater stability over time, which is evidence that the structure of the price generating process has changed, although in long term, the exchange rates have varied, in relation to the dollar, as much as in the pre-crisis period.

In order to investigate if the long memory identified for returns in the time period before the crisis was related to being inside the EMS, it was tested for long-memory in European currencies inside the European Monetary System using the R/S, GH and DFA methodologies. To test if the Hurst exponent found was significant, the standard errors were estimated using the post-blackening bootstrap approach, and afterwards, these errors were used in the calculation of the Wald statistics, defined as $W = \frac{(H - 0.5)^2}{(Std.ErrorH)^2}$, with 3.8 and 6.6 as critical values at the 5% and 1% level, respectively. These calculations led to an evidence of moderate long memory (see Table 6), which suggests that being inside the EMS increases predictability.

Table 6. Hurst exponents for different currencies (EMS)

Currency	DEM	DM1	FRF	GBP	ITL
Sample Begins	5/27/1986	5/27/1986	5/27/1986	5/27/1986	5/27/1986
Sample Ends	12/31/1998	12/31/1998	12/31/1998	12/31/1998	12/31/1998
Num. Obs	3169	3169	3169	3169	3169
R/S - H	**0.5802**	**0.5707**	**0.5760**	**0.5674**	**0.5984**
std. Error	0.0260	0.0264	0.0256	0.0262	0.0255
Wald	9.5033	7.1785	8.8486	6.6002	14.8878
GH - H	**0.5349**	**0.5193**	**0.5349**	**0.5342**	**0.5220**
std. Error	0.0082	0.0080	0.0080	0.0082	0.0083
Wald	18.1809	5.7768	19.1673	17.5948	7.0490
DFA - H	**0.5528**	**0.5401**	**0.5441**	**0.5639**	**0.5617**
std. Error	0.0060	0.0058	0.0058	0.0060	0.0064
Wald	78.2276	48.1996	57.2790	112.1918	93.2549

DEM, DM1, FRF, GBP and ITL stand for spot Deutsche mark, DM1 for the three-month futures contract on Deutsche mark, FRF for the spot French Franc, GBP for the spot British pound and ITL for the spot Italian Lira. Hurst exponents for each method, R/S, GH and DFA, are presented in bold.

6. Conclusions and final considerations

In this work, it was studied the evolution of long memory over time, in the returns and volatilities of the generic British pound futures contracts, negotiated on the Chicago Mercantile Exchange, from 1986 to 2004. As for the returns, it was verified that in the period that anteceded the European financial crisis, long memory occurred, which disappeared in the post-crisis period. In the case of the volatilities, long memory was identified. The results that were obtained for the unfiltered series were compared to those obtained for the filtered series for rolling maturities and the results were practically identical. Since the price of an asset on the spot market is used to establish the price of an asset on the futures market, it was verified whether the long memory evolution, for the spot exchange rate, and for the futures contract, were similar. The answer for this issue was positive.

The qualitative analysis of the evolution of the measurements of long memory in the pre and post crisis periods clearly exhibit the occurrence of a structural change after the crisis, which resulted in the elimination of long memory which existed in the pre-crisis period. This elimination is basically a result of the modification of the condition processes of the monetary policy in Great Britain, which occurred when this country left the EMS. It was more costly to speculate in the currency after the abandonment of the EMS. We also test for long-memory in European currencies inside the European Monetary system and find evidence of moderate long memory, which suggests that being inside the EMS increases predictability.

Our results suggests that the British pound against the US dollar exchange rate is multifractal[7], i.e., has a time-varying degree of long-range dependence and that structural changes in the economy (such as the abandonment of the EMS) has important implications on the dynamics of the exchange rate. This should be true for a variety of countries that have made similar adjustments and evidence for other countries would be particularly interesting.

[7] When a unique Hurst exponent is enough to characterize the richness of the time series, the time series is said to be a monofractal. Otherwise, several Hurst exponents are necessary to characterize the time series and the time series is said to be a multifractal. Muniandy et al. (2001) argue that a function or time series with singularity exponent that vary from point to point is said to be multifractal (See also Mandelbrot (1977)).

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