MEASUREMENT AND ANALYSIS OF THE SPANISH STOCK EXCHANGE USING THE LYAPUNOV EXPONENT WITH DIGITAL TECHNOLOGY

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De conformidad con la base quinta de la convocatoria del Programa de Estímulo a la Investigación, este trabajo ha sido sometido a evaluación externa anónima de especialistas cualificados a fin de contrastar su nivel técnico.

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Measurement and analysis of the Spanish Stock Exchange using the Lyapunov exponent with digital technology

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Abstract

This work tries to find some kind of non linear dependency on the Spanish Stock Exchange by using a metric test, the Lyapunov exponents. Although, there have been some studies that have tried to find out chaotic determinism by using this methodology, the results have not been very conclusive. These studies have used an analogical technology. Our goal is to find those exponents through the use of a digital technology that we have developed to avoid some of the adjustments and tune-ups previously required. To do so, we need to adapt some functions and data to financial time series. The result is not different than the one found in other Stock Exchange time series, namely, there is a chaotic signal in the Spanish Stock Exchange, albeit at high dimensions, and therefore, not feasible for obtaining risk-adjusted extra returns in an efficient financial market like the Spanish one.

Keywords

Non linearity, chaotic determinism, financial time series, digital technology
1. Introduction

Nowadays, there are many manuals that study non linear time series, including deterministic chaos and complexity structures within those time series. The methods that study these series can be broken down in classical statistics, metric, topological, and other methods (R/S analysis, 1/f noise, fractional Brownian motion, integrated fractional, series, statistical mechanics (SMFM), and the family of ARCH models, more related to classical statistics).

The metric methods measure the distances between points within an strange attractor, whereas the topological ones study the organization of the points within a strange attractor. Both groups of methods are specifically designed to study deterministic chaos. The most important topological methods are the recurrence tests and the nearest neighbours, whereas the most important metric tests are the correlation, capacity, information, and fractal dimensions, Kolmogorov entropy, and our focus of this paper, the methodology of the Lyapunov exponents. While the dimension gives us an estimation of the complexity of the system, the entropy and the exponents compute the level of chaos in the dynamical system. Although there are some packages of analogical software designed to try to calculate the exponents, their parameters require excessive tune-up. They are also very sensitive to noise. We expect to refine the procedure through the use of a digital technology that overcomes these problems. Therefore, the goal of this paper is to use a digital technology to find out the level of chaos in the Spanish stock exchange time series. This new approach, nevertheless, implies to carry out some adaptations.

Lyapunov exponents measure the mean exponential rate of divergence (or convergence) of two adjacent orbits (Fig. 1). They represent one of the basic characteristics of deterministic chaos: sensitivity to initial conditions. There are as many exponents as degrees of freedom. A negative exponent means that the trajectories converge in the same direction. This means that the signal has a mean reversion behaviour, leading toward a fixed point. If it were positive, then, the divergence become wider, confirming the chaotic behaviour hypothesis. The negative exponent compress the system, while the positive one
expands it (its sum is identical to the Kolmogorov entropy, which gives information about the reduction of the system predictability). In this way, only one positive exponent can show sensitivity to initial conditions, showing a “direction”. Therefore, the long term behaviour of any initial conditions specified with uncertainty can not be expected. In reality, this means that the behaviour is chaotic. If the result is infinite or goes to infinite, then, we have a random signal (assuming the corrections have been done correctly). If the result is null, then, the sequence is stable (periodic).

2. Background

Farmer y Sidorowich (1988) relate the exponents to the speculative bubbles, denying the use of financial models based on rational expectations. Therefore, the exponents measure, through the higher exponent, the amount of instability in the time series. Another more classical method is based on the probability distribution. As early as Mandelbrot, in 1963, observed that the frequency distribution of daily stock exchange returns has thick tails, assuming that the reason for this anomaly was speculative bubbles (Fama and French, 1996; Brock and Malliaris, 1991; Shiller, 1989). Nevertheless, others (Flood, Hodrick, 1986) think that the excessive time series volatility is due to a poor specification of the model.

In either case, the Lyapunov exponent (and the correlation dimension) has been used mainly in the field of Physics applied to the study of chaos. Their use, in financial or economical time series, requires an adaptation (Isham, 1993). Notwithstanding, this adaptation has generated high correlation dimensions, which means that the structure of the financial time series is closer to randomness than to deterministic chaos, and, as Brock and Sayers suggested (1988), this kind of tests to detect the existence of chaos in the time series is very weak. Gilmore(1992) points out that using this type of filters or adaptations affects not only the correlation dimension, but also the Lyapunov exponent. Due to little evidence of deterministic chaos at low dimension levels in the financial time series (Brock, 2000), other tests have been developed with the intention to discover and measure their level of non-
linearity (whiteness and random diagnostic). In this work, and following to Brock and Sayers (1988), we will increase the dimension in order to try to get the signal of the exponent.

The economic consequence of a certain deterministic chaos in the stock exchange time series will depend on the level of complexity of the dynamical system or the degree of their positive exponents. Nevertheless, many studies (see Brock, 2000) have already shown that, after considering trading costs, the capacity of obtaining risk-adjusted extra returns in efficient financial markets by using any chaos model is null. Therefore, research in this field is mainly academic and speculative. Chaos models, like other “quantum models”, are just tools that try to prove or disapprove the Efficient Market Hypothesis more than trying to forecast short-term future stock exchange returns.

In Spain, there are some research papers on deterministic chaos in financial time series (Blasco de las Heras, et al, 1995; Fernández Rodríguez y Martí 1995; and Olmeda & Pérez, 1995). They found, depending on the model, internal structures and non-linearity. Blasco et al. (1995), using the algorithm of Wolf et al (1985) to the IGBM (Madrid Stock Exchange General Index), and covering the period 1980-1993, showed exponents higher than zero in all cases studied, but without reaching any conclusion about a possible implicit determinism in the series due to the instability of the correlation dimension. They applied the standard methodology to different sets based in a sensitivity analysis, producing some results that support the weak presence of deterministic chaos. On the other hand, Bajo et al (1992) express the idea of chaos existence in exchange rate series. However, we must be cautious about the trustworthiness of the results because the number of samples and data is too small.

Brock, back in 1986, warned about the possibility of estimating artificially low dimensions due to the use of small economic and financial time series. Tata y Vassiliscos (1993) used the Lyapunov exponents on the NYSE covering over a century, with more than 29,000 observations, being the longest economic series ever used without finding any track of chaotic behaviour. However, when the series were divided in small samples, they found positive exponents, converging to zero when the number of observations in each sample is higher. They concluded that the positive results are consequence of using not enough data.
Brock and Sayers (1988) also concluded that, using financial time series of high frequency, chaos is “extremely improbable” due to the frictionless, and lack of measurement errors. For Jensen (1987), there is an indivisibility of the observed data that could alter any underlying chaotic process. Besides, when changes are very small, transaction costs made the chaotic mechanism very difficult to detect. Regarding the series frequency spectrum, it is convenient to check other kind of higher amplitude, because the daily ones are too noisy, although if the amplitude were too low, stationarity could ensued.

There are many ways to define the exponent (Lorenz, 1993; Gilmore, 1992; Dechert y Gencay, 1992) being the one of Wolf et al. (1985) the most used: “Giving a continuous dynamic system in a n-dimension space phase, the infinitesimal sphere of the initial conditions moves in an n-dimension ellipsoid object due to the deforming nature of the flux”.

The exponent $i$ of a dimension on terms of the extension of the ellipsoid principal axis

$$\lambda_i = \lim_{t \to \infty} \frac{1}{t} \log_2 \frac{P_i(t)}{P_i(0)}$$

where the exponents $\lambda_i$ are classify from high to small. As the ellipsoid orientation changes continuously, the direction associate to the exponent can not be defined. The linear relation of the ellipsoid grows at the rate $2^{\lambda_i} t$, the area defined by the two axes grows at the rate $2^{(\lambda_1 + \lambda_2)} t$, the volume defined by the three axis grows at the rate $2^{(\lambda_1 + \lambda_2 + \lambda_3)} t$, and so on. This property generates another definition of the exponent spectrum: the sum of the first $j$ exponents by the exponential growth rate.

An attractor of a dissipative system with at least a positive exponent is chaotic, and the sign (+/-) gives information about the quality of the dynamical system. The greater exponent will define the horizon of prediction further of what it is possible to predict.
Many researches have proposed algorithms to estimate the higher exponent, but they have been considered of little reliability, at least for small sets, and difficult to implement and compute. Other simpler methods, though, like the delay method are based on analogical methodology (Sato et al., 1987).

Our paper has adapted some of the techniques applied to evaluate analogical sequences to digital form. To do so, we have developed several programs to analyse different aspects of the sequence (neighbour search, distance measurement between neighbour processes, and finally, the Lyapunov coefficients. This process of subdivisions makes the development, checking, and implementation processes easier, avoiding the continuous use of commands to execute the subprograms. To do so, we have developed another “execute program” using Matlab, and whose parameters are the only functional data needed. This program is able to execute other subprograms: accumulate, cluster, configure, digitalize, statistic, lyp, series, and neighbour.

There are two basic methods to calculate the coefficients, and the selection of the most suitable depends on the knowledge about the signal generating equation. If it is known, the log of the derivative module of the equation that produces the signal for all range of starting values is calculated. If it is not known, then, the procedures have to be carried out directly on the whole data series using the mean of many starting points. The result, though, is similar to the one obtained with the derivative system. This second method, used in this paper, could, nevertheless, suffer some kind of upward bias due to the fact that the coefficients are calculated in a noisy system. Also, although we do not have a precise knowledge of the dimension of the financial time series (stock exchange returns and exchange rate changes), many research papers (Brock, 2000) have shown that the complexity or the underling dimension of the time series, is six, which it is much higher than previously thought.

Our goal is to find those exponents through the use of a digital technology that we have developed to avoid some of the adjustments and tune-ups previously required. To do so, we need to adapt some functions and data to financial time series.
3. Empirical Results

Starting with a dimensional set between five and seven, a system of starting point averages is used, from which a point and its neighbours are randomly chosen in such a way that its distance be inferior than a specific threshold $\varepsilon$. The difference between the following points of the series is calculated, using as the raw material the difference averages. Subsequently, the rate growth of the logarithm of the difference between steps is also calculated. But, for digital signals, as it is our case study, the calculation of the neighbours must be carried out for several points or dimensions $n$, with the intention to eliminate the risk that the sequence is not around such point and its neighbour. This process must be carried out especially with digitalized signals. The reason is that during the process of digitalisation, errors can be incurred. If the results are similar for some consecutive values, then, the conclusion is that we have being using correct values. But, on the contrary, if there is an increase in the coefficient values, then, we have being using erroneous values.

Another procedure can be carried out by finding the average of several starting points. However, for digitalized values, the difference with respect to a neighbour point could be zero, so that its logarithm comes near (-$\infty$) and, therefore, generating spurious results. To avoid this situation, a very high value is used (-100, -1000). No neighbour is produced if distances lower than the minimum difference between two sequence points are used. Finally, the factor starting point could be the key. The reason is that the final result could generate large changes; therefore, the operation is carried out using several and different starting points, and subsequently finding the geometric average among all of them. Due to all these conditions, it is advisable to carry out a sensitivity analysis, changing different values and study the results with the intention to delimit the measure process.

The program used in this paper is based in two parameters, the signal to be analized, and a value or mode to configure the Lyapunov coefficients. The total setup is made up of the following variables and vectors: The first number tells us about the kind of signal, analogical (1) or digital (0). The second value shows the maximum size of the signal used
(to calculate the Lyapunov exponents require, depending of the author, a lot of information). For Eckmann and Ruelle (see Rosenstein et al 1992), the size should be $N>10^D$, being $D$ the dimension). The third value represents the number of starting points needed to produce the average, being 50 by default. The four value specifies the minimum distance between neighbours, normally, greater than 0.001. Finally, the fifth value indicates the number of steps that the distance of differences is calculated for, generally, 30 or 50. Our paper calculates the maximum exponent as the slope of a linear regression model. Following the least square procedure, we adjust a straight line to the curve of a graph in which the logarithm of the divergence is set along the vertical axis, and the data returns are set along the horizontal axis. After a short review, we found out that the results are quite similar, independently of the volume used in the second parameter.

In a first phase, we use analogical non chaotic and chaotic time series produced by three standard equations with the intention of comparing graphically the different figures produced according to different procedures. Subsequently, we follow the same process, but this time using digital signals, and finding out the Lyapunov exponents. This experiment allows us to check, on one hand, if we can detect the chaotic signals as such, obtaining the expected results and, on the other hand, it allows us to see the way our system works with digital signals. In other words, if the process of digitalisation is correct.

Testing with analogical and digital signals

I) Non Chaotic signals

We run the program “to analyze” using the time series produced by the sinusoidal equations:

$$\sin(x*\pi/8)$$

And the additive sinusoidal

$$\sin(x*8)+\sin(x*\pi/100)+\sin(x*\pi/4)$$
II) Chaotic signals

Using the logistic equation

\[ x_{n+1} = A \cdot x_n \cdot (1 - x_n) \]

with parameters \( A=4 \) and 0.1 as the starting value \( X \).

Signals were digitalized for these calculations in \( 2^{16} \) levels. In other words, we used 16 bits, producing a distance between consecutive values of \( \frac{1}{2^{14}} \), using the remaining values as if they were analogical signals.

We have calculated 15,000 values for each series, from which we use the first 200 just to draw the graphs. We can see, through an analysis of the frequency domain that the sinusoidal profiles belongs thoroughly to a sine signal (fig. 2) and to a set made of the sum of three sine signals of different frequencies (fig. 3), representing expected and deterministic periodic functions. This clear-cut prediction can be seen in their corresponding Lyapunov coefficient graphs, with a naught value (the slope) for the sinusoidal signal (fig.4), and a negative value for the set signal. This negative exponent means that there is an approximation of trajectories in the same direction. In other words, the signal is convergent and not chaotic.

To verify our model, we have used the logistic equation, which is a one dimensional non linear difference feedback system. By changing the key variable, it can generate stable, deterministic, chaotic or totally random behaviour, and at some specific range variable, what apparently looks like a random time series, it has really hidden inside a deterministic chaotic dynamic. We can see that it generates a curve (fig.7) with a slope, defining the Lyapunov exponent, of 0.6914, very close to the theoretical values. The results are very similar to the ones obtained by Rosenstein et al (1992) in his work about exponents on small sets, in
numerical as well as graphical representation. Previously, they have conducted a sensitivity analysis about known chaotic generators, among them, the logistic equation. They used the methodology of Sato et al (1987) to several dimensions (0-5) and time series, calculating for each combination a range of exponents between 0.675 and 0.686, very similar to the 0.6914 found in our work. The small difference could be the result of not using the sixth dimension, which, according to Brock (2000), it should be the most useful.

After checking out that the program responded correctly to the digitalized signals, a sensitivity analysis procedure is carried out. The intention is, depending on the number of bits used, to find out the limitations of the configuration values. We have found the following effects:

1) Reduction of the distance between neighbours. This distance must be in line with the digitalisation of the signal. The reason is that the process of digitalisation requires a minimum distance below which there are not differences. For instance, if we digitalize using 8 bits, then, distances under 1/256 can not be found, due to the fact that a very short distance will produce, as a result, neighbours totally similar to base values.

2) Reduction of the number of starting points. If we do not pick up the right number of points, the result could be wrong. There is a correct number of points depending on any specific series.

3) Variation of the dimension. The best way to find out if the dimension is the right one consists in switching up and down the parameter and, from a specific value on, the result becomes stable.

4) The distance between neighbours. This distance should be sufficiently small. The reason is that the sequences might not have enough margin to diverge and, therefore, unable to be measured. On the other hand, if we use a too small a value, we might not find any neighbours, specially in the case of a digital signal.
5) The number of digital bits. We have observed that the results are quite poor if we use just 8 bits, but we obtain a much better representation by increasing it to 16 and 32.

The dataset used covers the period between 1986 and 2003, both years included. The raw material is the daily return of stocks defined as the logarithm of price differences. We just report the very well documented fact that the unconditional distribution of many financial series are leptokurtic, and the skew coefficients also differ from the ones corresponding to an normal distribution. According to Brock et al, (1991), this difference procedure do not affect the dynamical traits of a chaotic time series. Also, the augmented Dickey-Fuller test failed to reject the null hypothesis of a unit root in the series (see Olmeda and Perez, 1995).

The result can be observed in a graph, with the numerical estimations attached. The four series used are made up of two private companies, Telefónica (phone company) and Acciona (a construction and conglomerate firm), and two indices, the IGBM, (Madrid Stock Exchange General Index) with around 120 stocks, , not corrected for dividends or splits, and the Ibex 35, not corrected for splits (although it was created in January 1990, we have adapted it backwards).

The three key variables that produce information on the Lyapunov exponents are: the dimension, in our study, 3, 5, 6 and 7, the number of starting points used to calculate the mean (20 and 50), and the distance between neighbours (0,01, 0,005, and 0,001), giving within brackets the number of stock companies used in the sensitivity analysis. The total combination of variables to carry out the sensitivity analysis of the four series is 432, plus their attached graphs. Due to this problem, we include in our analysis only those combinations that produce new results. In short, we put aside persistent negative results with the intention of avoiding drawing too many useless graphs. For instance, the distance 0.001 does not produce any kind of information, therefore, we reject amplifying the sensitivity analysis with such parameter beyond a minimum requirement.
When changing the number of base values used to calculate the mean, from 50 to 20, within a minimum distance framework between neighbours of the average level, the Lyapunov exponent of Acciona changes from naught to positive. We speculate with the idea that, by being Acciona a relatively volatile stock, and by using too many stocks to calculate the mean within a short distance framework, our method will not be able to find the exponent. Notwithstanding, the signal is recorded when the minimum distance between neighbours goes up to 0.01. Telefónica, on the other hand, shows the exponents at dimensions beyond five, independently of the number of starting points used, although, the signal is lost when the minimum distance between neighbours is too short (0,001) (fig.8-18). This last result happens to be similar for all series. Therefore, we can assume that the coefficients signal requires a distance longer that this minimum. The IGBM shows, in a range of dimensions (3-6), a lack of signal, even within the framework of the largest minimum distant of 0,01. However, the Ibex 35, at dimension six, considered to be the most reliable one, shows signals of exponents not only for the minimum distant but for the intermediate one as well.
4. Conclusions

Using a digital methodology, we confirm the results found in other stock exchange time series, namely, that there is a chaotic signal in the Spanish Stock Exchange, albeit at high dimensions. However, when we split the series between single and collective ones, such signals can be obtained in dimension five for single series, and dimension six for the collective. This result could be due to a weak signal. A hypothesis is that the variations in the 120 stocks that make up the IGBM, and in the 35 of the Ibex compensate for each other through internal correlations, In doing so, the chaotic signal could be harder to find, requiring, thus, higher dimensions than the ones required for individual stocks.

As we have previously mentioned it, when we increase data frequency, short memory tends to disappear, emerging, notwithstanding, a kind of autoregressive process. Its significance, by using quarterly data, however, is almost zero, surging, on the other hand, a process of long memory. Blasco de las Heras and Santamaría (1994a) already reported about the existence of such memory, questioning, along most researchers, the veracity of their results in their search of chaotic behaviour in stock exchange time series. Following the advise of Brock (1986), the sampling raw material should be based on monthly or quarterly data, and covering as many decades as possible. In our case, it becomes specially worrisome, and the reason is that the times series data of the Madrid Stock Exchange is not only short but somehow noisy, and the low frequency needed could make the time series unfortunately even shorter, with not use for further analysis.

Finally, the searching of chaotic signals before the initiation of the Madrid Stock Exchange General Index, and the Ibex 35 in 1986 and 1990 respectively, would have been of little use due to their not so transparent and efficient nature. In this fashion, we find ourselves with the discovery, by using analogical and digital technology, chaotic signals in very high dimensions, without the capacity to really verify if it is the result of an authentic chaotic or just a noisy process of some kind.
Graphs

Figure 1. Two neighbour trajectories in an attractor showing the divergence trait across time and associated to a chaotic behaviour.

Fig 2: First sinusoidal.  
Fig 3: Sum of sinusoidals
Fig 4: Sinusoidal Lyapunov coefficients

Fig 5: Sinusoidal sum of Lyapunov coefficients

Fig 6: Logistic function

Fig 7: Coefficients of the logistic function

Fig 8 dimen=[3]; IGBM
lya=[1 25000 50 0.01 50];

Fig 9 dimen=[6]; IGBM
lya=[1 25000 50 0.001 50];
Fig 16 dimen=[6]; lya=[1 25000 50 0.01 50];

Fig 17 dimen [6]; lya=[1 25000 50 0.005 50];

Fig. 18 dimen lya=[1 25000 50 0.01 50];


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