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1 Introduction

This paper develops and applies a stochastic geometry approach designed to describe the dynamics of the object emerging from the collective behavior of a complex system. In the current case, the market is analyzed according to the evolution of the population of 19 stocks of the PSI20 index for the period from October 2006 to April 2008.

For this purpose, we apply a methodology previously developed in other work ([1], [2]), in order to compare the dynamics and namely the changes in the evolution of the Portuguese financial market, as described by the index representing its most important firms. In the second section, we briefly recapitulate the methods and previous results, whereas in the third section the method is applied to the PSI20 data and the results are compared to our previous conclusions as obtained from the US market.

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We define a metric and use a properly defined distance, computed from the correlation coefficients between daily returns of the stocks. We proceed to the identification of the geometric object formed by the set of distances among such firms. The results prove that the resulting ellipsoid is a cloud of points, which is uniformly distributed along its first leading directions, whenever business-as-usual predominates, but that it is suffers severe distortions along several dimensions whenever a crisis occurs. The geometric properties of the dynamics of this market can be measured and guide an empirically oriented interpretation of its evolution ([1], [2]).

The approach we suggest allows for:

1. the identification of the minimum number of relevant dimensions describing the evolution of the market;

2. the identification of the dimensions along which the distortion occurs and

3. the measurement of the effect of that distortion

2 The stochastic geometry approach

Unless the proportion of systematic information present in correlations between stocks in a complex system is relatively small, the corresponding manifold is a not a low-dimensional entity and therefore its understanding is virtually unreachable. But the evidence of alternate states of apparent randomness and the emergence of structured collective dynamics suggests it may correspond to a low-dimensional object. The rationale for this intuition is as follows: considering the existence of competition among multiple agencies, firms, information and strategies, the response by the agents to the multiple signals can create an object comparable to that obtained from random processes, which is a powerful analogy for such markets except when collective behavior emerges and dominates its dynamics. If this is the case, the relevant point is to capture this evolution and we are reduced to an embedding question, the definition of the smallest manifold that contains the set of points describing the market. In that case, its dynamics can be observed as its form is shaped by the occurrence of bubbles and crises.

The stochastic geometry strategy is simply stated in the following terms.

2.1 The metric and the definition of a distance

From the set of returns of the stocks and their historical data of returns over the time interval, and using an appropriate metric ([3],[4]), we compute the matrix of distances between the stocks. Considering the returns for each stock,

$$r(k) = \log(p_t(k)) - \log(p_{t-1}(k)) \tag{1}$$

a normalized vector

$$\overrightarrow{\rho}(k) = \frac{\overrightarrow{r}(k) - \left\langle \overrightarrow{r}(k) \right\rangle}{\sqrt{n\left(\langle r^2(k)\rangle - \langle r(k)\rangle^2\right)}} \tag{2}$$

is defined, where n is the number of components (number of time labels) in the vector $\overrightarrow{\rho}$. With this vector the distance between the stocks k and l is defined by the Euclidian distance of the normalized vectors.

$$d_{ij} = \sqrt{2\,(1 - C_{ij})} = \| \overrightarrow{\rho}(k) - \overrightarrow{\rho}(l) \| \tag{3}$$

as proposed in [3] and [4], with C_{ij} being the correlation coefficient of the returns $r(i)$,$r(j)$.

2.2 Identification of the relevant directions and the index S

As the distance is properly defined, it is possible to obtain, from the matrix of distances, the coordinates for the stocks in a Euclidean space of dimension smaller than N. Then the standard analysis of reduction of the coordinates is applied to the center of mass and the eigenvectors of the inertial tensor are computed.

The same technique is applied to surrogate data, namely to data obtained by independent time permutation for each stock and these eigenvalues are compared with those obtained in from the data, in order to identify the directions for which the eigenvalues are significantly different.

For both surrogate and actual data, the sorted eigenvalues, from large to small, decrease with their order. In the surrogate case, the uniform decrease of the eigenvalues shows that the directions are being extracted from a spherical configuration, corresponding to the randomness of the configuration. The display of a uniform and smooth decrease in the values of the sorted eigenvalues is characteristic of random cases and is also experimentally observed when the market space is built from historical data corresponding to a period of business as usual.

The procedure is straightforward. After the distances (d_{ij}) are calculated for the set of N stocks, they are embedded in R^D, where $D < n$, with coordinates $\overrightarrow{x}(k)$. The center of mass $\overrightarrow{R}$ is computed and coordinates reduced to the center of mass.

$$\overrightarrow{R} = \frac{\Sigma_k \overrightarrow{x}(k)}{k} \tag{4}$$

$$\overrightarrow{y}(k) = \overrightarrow{x}(k) - \overrightarrow{R} \tag{5}$$

and the inertial tensor

$$T_{ij} = \Sigma_k \overrightarrow{y_i}(k) \overrightarrow{y}_j(k) \tag{6}$$

is diagonalized to obtain the set of normalized eigenvectors $\{\lambda_i, \overrightarrow{e}_i\}$. The eigenvectors $\overrightarrow{e}_i$ define the characteristic directions of the set of stocks. The characteristic directions correspond to the eigenvalues (λ_i) that are clearly different from those obtained from surrogate data. They define a reduced subspace of dimension f, which carries the systematic information related to the market correlation structure. In order to improve the decision criterion on how many eigenvalues are clearly different from those obtained from surrogate data, a normalized difference τ is computed:

$$\tau(i) = \lambda(i) + 1 - \lambda'(i) \tag{7}$$

and the number of significantly different eigenvalues is given by the highest value of i to which $(\tau(i) - \tau(i-1)) > 3(\tau(i+1) - \tau(i))$.

It was empirically found that markets of different sizes, ranging from 70 to 424 stocks, across different time windows (from one year to 35 years) and also from different market indexes[1] have only six effective dimensions ([5], [1], [2]).

This corresponds to the identification of empirically constructed variables that drive the market and, in this framework, the number of surviving eigenvalues is the effective characteristic dimension of this economic space. Taking the eigenvalues of order smaller or equal than the number of characteristic

[1] stocks from the S&P500 and Dow Jones indexes were considered

dimensions, the difference between eigenvalues from data and those obtained from surrogate data are computed. The normalized sum of those differences is the index S, which measures the evolution of the distortion effect in the shape of the market space.

$$S_t = \Sigma_{i=1}^{6} \frac{\lambda_t(i) - \lambda'_t(i)}{\lambda'_t(i)} = \Sigma_{i=1}^{6} \frac{\lambda_t(i)}{\lambda'_t(i)} - 1 \tag{8}$$

where $\lambda_t(1), \lambda_t(2), ..., \lambda_t(6)$ are the six largest eigenvalues of the market space and $\lambda'_t(1), \lambda'_t(2), ..., \lambda'_t(6)$ are the largest six eigenvalues obtained from surrogate data. In computing S, at a given time t, both λ_t and λ'_t are obtained over the same time window and for the same set of stocks.

3 The dynamics of the Portuguese financial market

This method is applied to the data describing the daily evolution of the PSI20, the index representing the major players in the Portuguese stock market. In Figure 1, we show the object describing the evolution of the market as replicated in the three dominant directions, as obtained following the method indicated in the last section, and the object of a period of business-as-usual is compared to another formed in a period of crash. The differences are imposing, since in the latter type of situation the clustering of firms (colored accordingly to the sector they belong) and the deformation of the market space are obvious.

The object has a characteristic dimension, which allows for a description projecting its typical shape and the identification of the patterns of its evolution. The index S is useful for this identification of shapes and patterns and the results of its computation for the whole period are indicated in Figure 2, in which the impacts of the subprime crisis is evident (Fig. 2). The index provides information on the evolution of the object describing the dynamics of the markets. It indicates the moments of perturbations, proving that the dynamics is driven both by shocks and by structural change. This is graphically evident in Figure 2 and is confirmed by the rigorous measurement of the distortion of the shape of the object describing the market. The previous results suggest that, as the markets suffer a crash, there is a distortion in the dominant directions representing its leading variables.

The changing patterns for this period are notorious. In Figure 1, we show the object describing the evolution of the market as replicated in the three dominant directions, as obtained following the method indicated in the last section, and the object of a period of business-as-usual is compared to another formed in a period of crash. The differences are imposing, since in the latter type of situation the clustering of firms (colored accordingly to the sector they belong) and the deformation of the market space are obvious.

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4 Conclusion

The measurement proves that the Portuguese financial market is a follower, as expected. The impact of the major international crises is immediate, eventually majored by local reasons and the vulnerability of a small, peripheric and dependent market. the structure of the process is comparable, in spite of this difference in dimension and the centrality of the US market for the functioning of the world financial system.

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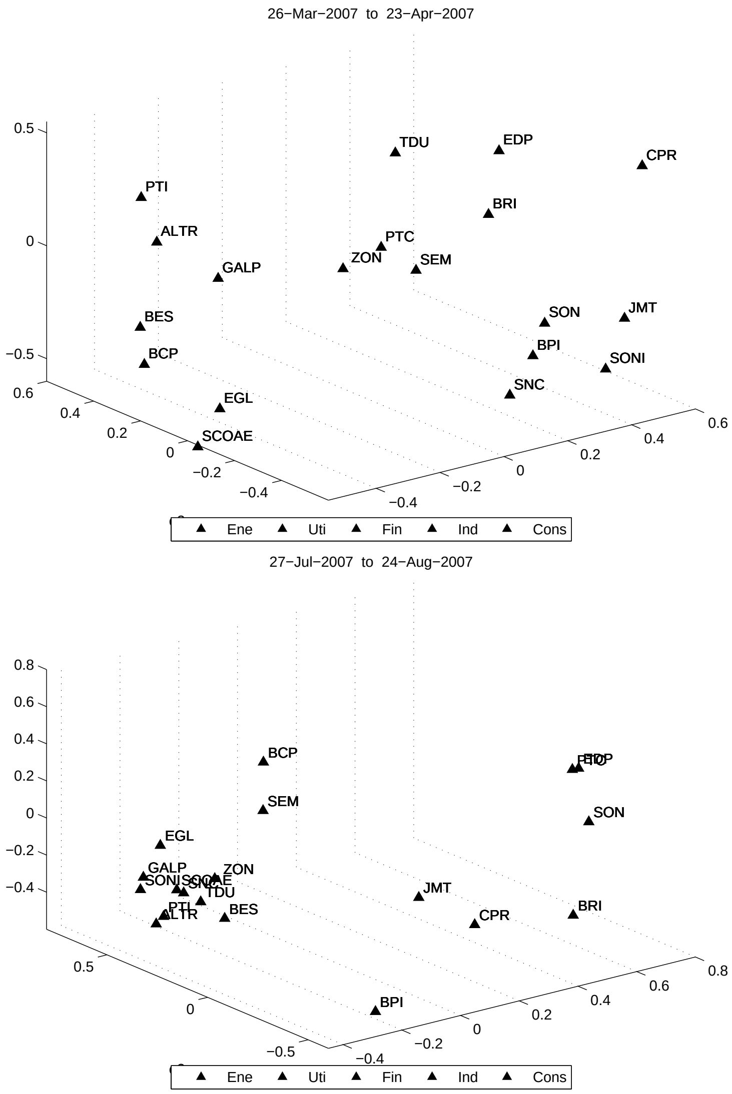

Figure 1: Market space described along the three dominant directions, for a period of business-as-usual and for a turbulent period

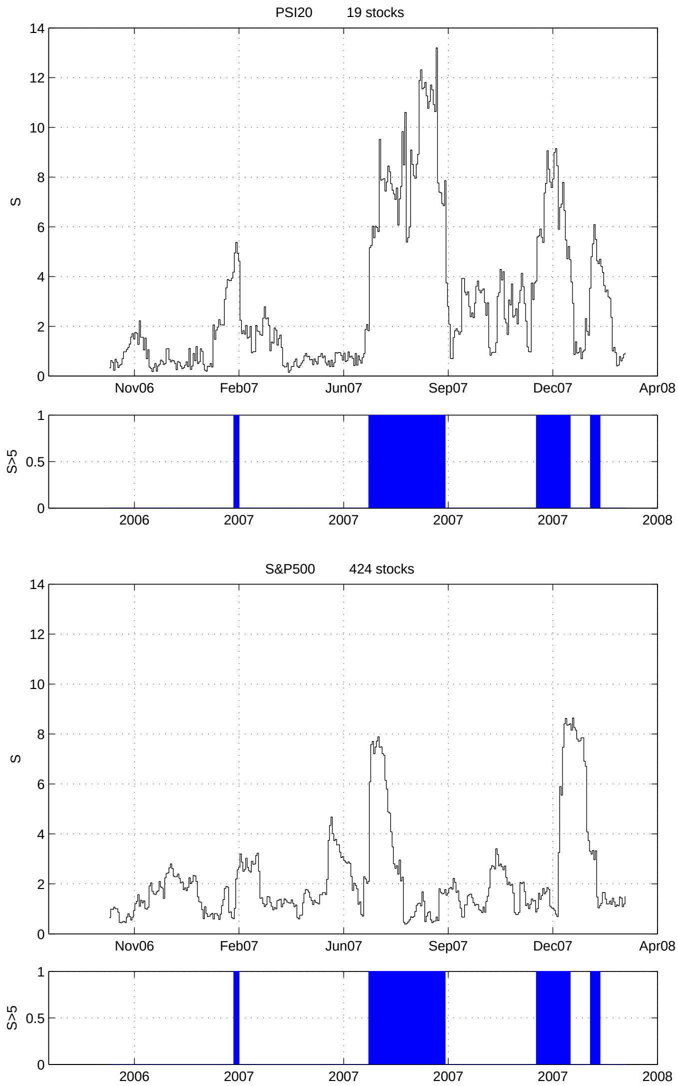

Figure 2: The evolution of the index S measuring the evolution of the PSI20 structure for 2006-2008 and comparison with the S&P500 describing the USA market