THEORY OF CHAOS APPROACH TO ASSESS THE MANAGEMENT DECENTRALIZATION

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Pe baza unui model matricial original, autorii folosesc, în această lucrare interdisciplinară, conceptul de econofizică precum şi noţiunea de structură fractală – care fost extinsă cu scopul de a se identifica proprietăţi ale sistemelor economice. Deoarece teoria haosului poate fi o abordare valabilă pentru explicarea unor evenimente care altfel ar rămâne adânc ascunse într-un complex de informaţii, sunt aplicate teoria haosului şi analiza neliniară. Este propusă o metodă originală pentru determinarea gradului de descentralizare managerială. Această metodă este aplicată pentru investigarea seriilor de date cronologice relative la cursul de schimb valutar în 26 sisteme economice într-o perioadă de 12 ani. Rezultatele susţin aplicabilitatea modelului şi a metodei propuse.

Based on an original matrix model, this interdisciplinary paper uses the concepts of econophysics and fractal structure, which has been extended to read out properties emerging from the economic systems. As the theory of chaos could be the solution for explaining unlikely events that remain otherwise deeply hidden in a complex information mixture, a chaotic approach and a nonlinear analysis are performed. An original method to assess the degree of management centralization is proposed. This method is applied to investigate the time series of the exchange rates for 26 economic systems over 12 years. The results support the model and method applicability.

Keywords: Econophysics, matrix economic model, centralized/decentralized management, time series, correlation dimension

1. Introduction

Econophysics [1] mainly consists of physico-mathematical models that apply to the markets. The concept of fractal structure has extended to read out functions emerging as time series from the economic systems, the exchange rate being one of the most available parameter. It has largely been proved that the chaotic approach could be the solution for explaining unlikely events that remain otherwise deeply hidden in a complex information mixture.

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Real economic systems are essentially non-linear and their extremely sensitive evolution to the starting conditions is often characterized by strange attractors, which yield a balance between centralized management of the government tending to preserve economic stability, and distributed autonomy of the enterprises dealing with profit and growth [2]. This work is focused on the persistence of the strange attractors [3] with respect to a trend removal procedure – whose rejection effectiveness applies to periods longer than one quarter or 90 days.

The time series of the currency exchange rates of 26 economic systems exhibiting stable properties over 12 years were analyzed, proposing a partition scheme according to the persistence of the reconstructed strange attractors versus the trend removal procedure. The persistence is estimated using a novel criterion of achieving the threshold characterizing the "colored noise" for the correlation dimension. The monetary systems delimited by the Euro Zone (EZ) and North Korean economy are chosen as references for the decentralized and centralized management respectively. EZ is taken as reference for decentralization - due to its low degree of integration with respect to any other country (including the federative states).

The scores from the "Index of the Economic Freedom" served as controlling indicator for the study. The model is fitting well the most part of the countries but noticeable differences are also revealed. The yearly Index of the Economic Freedom - IEF published by Heritage Foundation and Dow Jones & Company, Inc. [20] is providing a useful picture of more than 160 countries against a list of 50 independent variables divided into 10 broad factors of economic freedom. The equally weighted factors are aggregated in a single one, namely the aggregate IEF as a percentage of the ideal, absolutely free economy - characterized by perfect competition [4] with unitary index. The lower the score, the less economic freedom a country enjoys. It is widely accepted that a functional market economy is a good argument for an effective mind-to-market cycle supporting the innovative capability of the undertakers and therefore being considered as a key driver toward the knowledge-based economy of the respective region [5]. There are two factors, which are utmost interesting in the present work because of their potential to influence the market functionality: the property rights regime (PRR) that essentially determines the management type (in IEF sense), and the share of the state owned property through the state owned enterprises (GOV).

PRR and GOV complete a two dimensional matrix model furnishing a more detailed breakdown of the variety of the economic systems existing in the world. The matrix economic model (Scarlat) was previously applied in case of Romanian economic transition ([6], [7], [8], [9], [12]) or its privatization component [10] as well as other countries [11].

The purpose of this research work is to propose a method – based on the chaos theory – to assess the degree of centralization that characterizes the management of any economic system.

The methodology includes: development of the quantitative instrument (persistence of the strange attractors with respect to a trend removal procedure); selection of the proper sample of economic systems (26 economic systems – 25 countries plus Euro Zone); validation of the method by comparing the results obtained against IEF ranking, with the support of the matrix economic model.

This paper is largely based on a previous research report presented by the authors [13].

The paper structure follows the research methodology:

- Chaos theory approach – to determine the level of management decentralization
- Data collection
- Results
- Discussion: comparing the results with the existing IEF factors that matches the best the proposed issue, using the matrix economic model

The conclusions complete the paper.

2. Chaos Theory approach – to assess management decentralization

The present paper is an attempt to offer an alternate projection of the same reality on quantitative bases by using the chaos theory [14]. The Hurst exponent is used, the correlation dimension and, implicitly, the embedding dimension as minimal characterization of the chosen macroeconomic systems as reflected in their exchange rate series.

The analysis procedure is not to directly characterize the given dynamic system, which remains mostly unknown, but an image-system with the same topology that preserves the main characteristics of the genuine one. As stated in literature, such an image system and its corresponding phase space can be built according to the Whitney-Takens' embedding theorems [15]. The correlation dimension is characterizing the attractor set (if any). The geometrical shape of the attractor set in the phase space determines the complexity of the underlying dynamic system.

For a time series with N elements the correlation sum is:

$$CorrD(N,m,\varepsilon)=\frac{1}{(N-m+1)(N-m)}\sum_{k=1}^{N-m+1}\sum_{j=1}^{N-m+1}\eta\left(\varepsilon-\left\|\boldsymbol{x}_k^{\text{rec}}-\boldsymbol{x}_j^{\text{rec}}\right\|\right), \quad (1)$$

where η is the step unity function (or the Heaviside function), i.e. it is 1 for positive arguments and 0 otherwise, ε an arbitrary positive scalar, and $\boldsymbol{x}_k^{\mathrm{rec}}$ and $\boldsymbol{x}_j^{\mathrm{rec}}$ are two vector points belonging to the reconstructed trajectories in the embedding *m*-dimensional space according to the reconstruction method (x12). Finally, the correlation dimension *CorrD* is the following limit:

$$CorrD = \lim_{\varepsilon \to 0} \frac{\log C(N, m, \varepsilon)}{\log \varepsilon} \tag{2}$$

A correlation dimension greater than five implies the prevalence of colored noise [14]; therefore we consider tangibility of the threshold:

$$CorrD_{\mathrm{th}}=5 \tag{2'}$$

as the pointer for assessing to what extent the management could be or not considered as centralized and thus contributing to distinguish the basic categories of markets.

Time series are often characterized as "biased random walks" – trends with noise – with root mean square fluctuation range increasing with time as n^H where *H* is the well known Hurst exponent [16]. The proper range for *H* is from 0, corresponding to very rough random fractal curves, to 1, corresponding to rather smooth looking fractals. $H<0.5$ indicates the antipersistence of the series, while $H>0.5$ points out positive time correlation of the consecutive samples. For a true random walk $H=0.5$ and the samples are uncorrelated.

Technically, any time series (log values) is considered as a linear superposition of long run trend and residual variations. In the case of the exchange rate parameter:

$$\{\text{EXCHANGE RATE}\} = \{\text{TREND}\} + \{\text{RESIDUALS}\} \tag{3}$$

In a condensed notation

$$\{x(n)\} = \{\theta(n)\} + \{r(n)\}, \quad n=1,\ldots N, \tag{3'}$$

where *x,* θ*,* and *r* are the samples of the exchange rate, of the trend, and of the corresponding residuals, respectively, and *n* stands for the discrete time. The trend is least squared error sum (LSE) approximated as a *G*-order polynomial:

$$\{\theta(n)\} = \sum_{k=0}^{G} b_k n^k \,,\ n=1,\ldots N, \tag{4}$$

where b_k are the corresponding coefficients, and $G \leq 85$. For approximately 4200 points in the series, the degree of 85 is associated with attenuation factor of ten of the period of 90 days with respect to the longest period of 12 years (Appendix). The typical time interval after which the economic indicators are measured and the business cycles are evaluated is the quarter [17] - three months or 90 days.

The assessment of the three months anchor objectives leads to the decision to change, or to modify parts of the plans, or to go on with corrections and upgrades. The significance of Eqs. (3) and (3'), and taking into account Eq. (4), is described as follows.

- Trends $\{\theta(n)\}$ are carrying on the long range correlations as the effect of planning. Planning is the "sine qua non" instrument for implementing a developing strategy. Every economic agent has a certain strategy to obtain profit. The bigger the company, the longer the time horizon of the plan and the higher the impact of the managerial decisions [18]. Since $G \leq 85$ the trend is carrying on the planning effects over at least a quarter: the higher the order of the polynomial, the shorter the cycle that could be rejected (Figure 1).

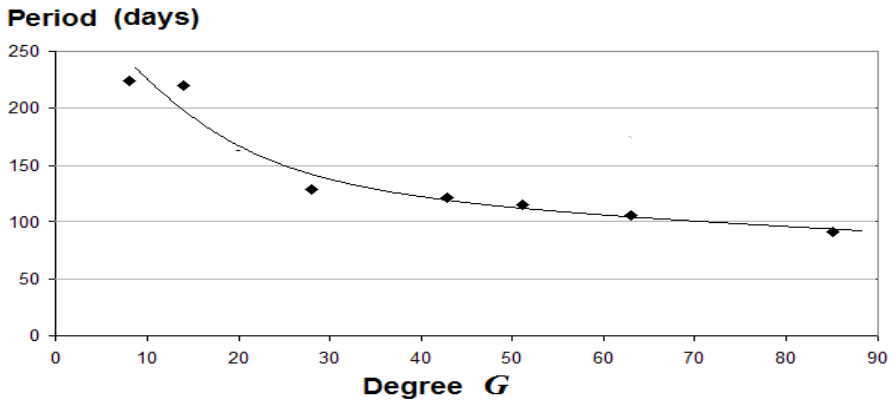


Fig. 1. The shortest period that could be rejected vs. the degree of the de-trending polynomial G approximating a gap of 90 days

- Residuals are preserving the short-range correlations of the market. After removing the long run planning effects from the exchange rates, the residuals are mostly influenced by the actions of the very small firms and individuals. One should note that the trend removal procedure is acting like a filter adapted to the spectrum of the series. Formally the residuals could be put in the form:

$$\{r(n)\}_G = \{x(n)\} - \sum_{k=0}^{G} b_k n^k \ , \quad n=1,\ldots N \tag{5}$$

By short run analysis on the residuals, one could reveal the following two extreme cases.

1° Residuals are exhibiting noisy features if for every time delay $\tau \in \{1; 2; 4; 8\}$ there is a value $G \leq 85$ such as $CorrD_{\text{th}}$ is reached. The noise is understood here as colored noise with zero mean whose characteristics will not be further analyzed here. We consider the noise to be the fingerprint of the market competition due to the efficient market hypothesis [19]. Decentralized management means that in a stable business environment, every undertaker is autonomously choosing the best way to maximize the welfare by taking the appropriate vital decision for his business, and these decisions are different to each other, under the forces of the competitive market. The differences in decisions are the consequence of having profit at the level of each economic entity; a mandatory prerequisite is to closely monitor the competitors and to decide on the bases of the currently available information. Such economic systems are characterized by *decentralized management.*

2° Residuals are not of a noise type since the threshold cannot be reached whatever the degree G at maximum delay $\tau=8$ (implying the threshold intangibility for all other smaller time delays) preserving the low dimensional attractor in the structure of the residuals. It is easy to verify that a perfect economy of command that maintains a constant exchange rate obeying a Dirac probability distribution function (like the exchange rate North Korean Won against USD between 1997 and 2007) is fulfilling this condition. When not reaching at all the noise features for the residuals, we assume the centralized management of the government is penetrating down to the plans shorter than the quarter, aiming to homogenize the behavior of undertakers whatever their sizes. The requirement to be economic efficient moves the focus from the level of the sole entity to the greater levels limited by the national level. It would be the extreme case when the market is inside a national holding where only its efficiency counts. Lack of noise is consistent with the absence of fluctuations originated in the business freedom at the individual level – as a sign of significant involvement of the government in the economy. These economic systems are characterized by *centralized management.*

3° Intermediate category includes all systems between centralized and decentralized management. For sure, none of the real economies are perfectly "free" (decentralized) or "unfree" (centralized). The free-market economy is the closest to the efficient market hypothesis due to its motivation and flexibility mechanisms; in fact, it is rather a monopolistic competition than a perfect one. On the other side, the opposite situation is the economy of monopoly, when the case of state

monopoly - i.e. the case of the economy of command - is best fitting the theoretical model of a unique powerful competitor. However, the national exchange rate dynamics is the expression of many factors – out of which the economic productivity is the most important. Consequently, there are intermediate cases ranging between 1° and 2° when the noise threshold is found for $G \leq 85$ only for one, two or three larger values of the delay time i.e. $\tau \in \{2; 4; 8\}$. We call qualify this group as being characterized by *intermediate management.*

3. The assessing criterion

The chaotic dynamics analysis over the residuals $\{r(n)\}$ of 25 countries and EZ is completed by computing the Hurst exponent H and the correlation dimension *CorrD* for the reconstructed attractor. The technique consists in progressively de-trending of the series by increasing the degree of the polynomial; this is equivalent to shortening the time correlation in the series. For each G we vary the time delay of 8, 4, 2 and 1 day and compute *CorrD* up to reaching the threshold given by Eq. (3'), if possible; the corresponding G and τ will be marked.

The assessment criterion takes into account the attainableness of the threshold. A correlation dimension less than five for the residuals is interpreted as a significant influence of some market leaders that is reduced number of the variables characterizing the attractor; it is very likely to be a single one endowed with extreme economic and political potential to influence the behavior of the whole market: the government.

4. Data collection

All the data represent daily exchange rates of the respective national currencies against the USD (according to the IEF 2008 the US economy is 80.6% free), according to [21]. In order to have relevant data and to fulfill the minimum number of samples required by the non-linear processing, there were selected countries exhibiting a certain degree of stability of their economies over the last twelve years (i.e. from 1 January 1996 until 31 December 2007).

Therefore, the research focused on twenty five states that: *i)* did not change the currency, and *ii)* did not change significantly the IEF category in the last decade. They are: two "free", four "mostly free", nine "moderately free", seven "mostly unfree", and three "repressed". A significant number of the European Union member states could not qualify since they adopted the Euro currency at the 1st of January 1998 and gave rise to EZ. Nevertheless, the EZ is considered here to be the 26th economic system as a special representative of an economic system with decentralized governance and decision making on a quite fragmented market. The research interval for the Euro-USD exchange rate is shorter (i.e. 1 January 1998 – 31 December 2007).

5. Results

All types of management discussed before were found (Table 1). For the decentralized management group, the evolution toward the colored noise is interpreted in the sense of the existence of a biasing free competition market where the huge number of small entities (micro-enterprises and individuals) are performing economic activities over which the planned business of the more powerful companies are superimposed in a linear manner; it is worth noting that these significant competitors are exclusively using open market instruments that do not hinder the competition nor influence the accurate economic behavior of any agent. The government involvement is restricted at minimum. Oppositely, in case of the centralized management group, the persistence of the attractor in the domain of less than 90 days planning indicates a quasi-similar behavior of the agents whatever the size.

Table 1

Between centralized and decentralized management

Centralized management	Intermediate management			Decentralized management
	Mostly centralized	Moderate	Mostly decentralized	
Brazil	Hong Kong	Korea	Saudi Arabia	Japan
Egypt	Taiwan	Kuwait	Israel	Singapore
Nigeria	South Africa	Fiji	Philippines	United Kingdom
India	Peru			Denmark
China	Indonesia			Norway
Venezuela				Mexico
Iran				Euro Zone
North Korea				

The linear decomposition seems to be irrelevant with respect to the intricate influence impregnating the whole system. The channels of influence are not only economic, but largely non-economic and the government most likely acts in such ways by inhibiting information, restricting economic activity, and thus inhibiting the economic freedom. Government control can be exercised by explicit price control, interventions in the stock market, property rights regulations, etc. It is the case of North Korea, Venezuela, Iran, but also Nigeria, Egypt, and China. It is not very surprisingly that India and Brazil are also included in this category since they are indeed in the lower part of the IEF ranking.

For the intermediate management group, the attractor could be only partially removed. The group is in turn split in three subgroups (Table 1): Israel, Philippines and Saudi Arabia (mostly decentralized) are reaching the threshold only for delays of 2, 4, and 8 days. A particular case is Saudi Arabia for which the de-trending procedure has no effect, or, equivalently, $\{r(n)\} \cong \{x(n)\}$. The

particular stability of the exchange rate Saudi Rial/USD relies in relatively low control of the imports, and the availability of the oil (about 80% of the exports).

The subgroup of Korea, Kuwait and Fiji (moderate) has an oscillatory variation such as the threshold values are occasionally passed forth and back over the threshold for two values τ=8 and τ=4; consequently the attractor still exists as in the previous case, but the conclusion is that government influence is smaller.

Finally, Hong Kong, Peru, South Africa, Indonesia and Taiwan (mostly centralized) are exhibiting a single override of the threshold in the form of a local maximum and this occurs for τ=8. As example, Figure 2a illustrates the case of Indonesia for all the delays used.

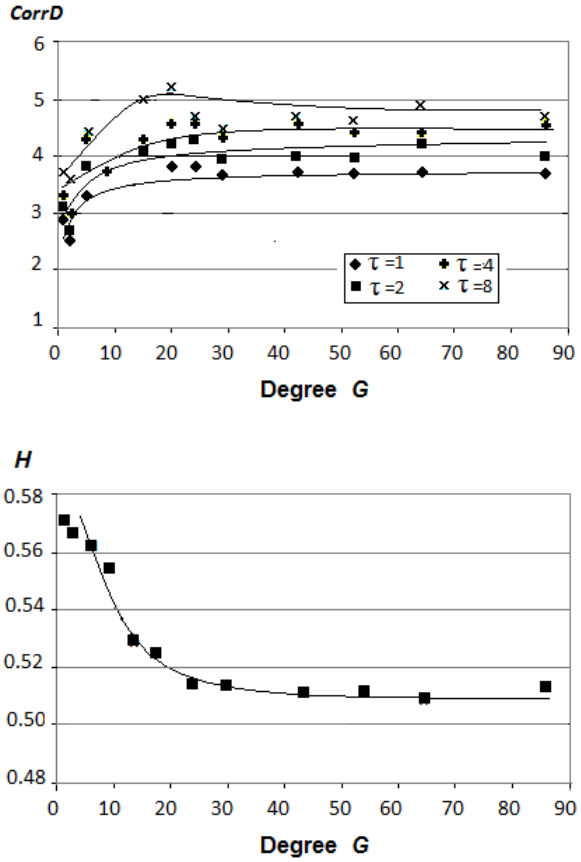


Fig. 2. The case of Indonesia – the correlation dimension *CorrD* variation (a), and the Hurst exponent *H* (b) against the degree *G*

The Hurst exponent is almost continuously decreasing with the degree of the polynomial, reducing the persistence of the series (this is a generally valiant result); the exception may occur in the same way as the transitory overtaking of the *CorrD* threshold for τ=8: since the LSE fitting is not a perfect one and the subtraction is in fact an additive operation with the corresponding opposite term, the residuals in Eq.(5) may contain new signal introduced by the polynomial itself, which did not belong to the genuine samples. This effect induces deviations from the monotonous variation of the measured data.

A general remark is the evolution toward the anti-persistent residuals when de-trending with higher and higher polynomial degree. A second remark is that value of *H* is reaching constant value when *CorrD* behaves oscillatory; therefore the constant value of the Hurst exponent indicates the beginning of the de-trending inefficiency (Figure 2b).

The method is neatly confirmed by the extreme results obtained: *i)* North Korea belongs to the centralized management group, and *ii*) EZ is representative for the decentralized management.

6. Discussion

In order to have a controlling instrument for assessing the management decentralization, the relevant IEF variables related to management should be identified. According to their definitions and among the ten equally weighted factors used in the IEF ranking, three of them are considered as the most relevant: property rights regime (PRR – IEF factor no. 8), capital flows and foreign investment (FIN – IEF factor no. 5), and doing business (BUS – IEF factor no. 9). Table 2 depicts the IEF ranking of the 26 economic systems considered, according to the three IEF indicators, plus the share of the state owned property through the state owned enterprises (GOV).

The relevant IEF factor to describe the management decentralization

PRR examines the extent to which private property is protected such as citizens are confident to undertake commercial activities, save their income, and make long-term plans because they know their income and savings are safe. PRR measures the independence of the judiciary system and the level of the freedom of any owner to decide on his property. This has direct influence on the planning decisions and the ability of individuals and businesses to enforce contracts taking into account the existing guarantees against possible expropriations. Thus, PRR is serious candidate to characterize the management type. The remaining two, FIN and BUS, are rejected because of their redundancy with PRR [13].

Table 2

IEF indices – aggregate, PRR, BUS, FIN, and GOV, for 26 economic systems

Economic system (symbol)	IEF factors [% free, 2007]				
	Aggregate IEF	PRR	BUS	FIN	GOV
Hong Kong (HK)	89.3	90	88.3	90	91.6
Singapore (Sin)	85.7	90	94.6	80	84.2
United Kingdom (UK)	81.6	90	92.1	90	54.2
Denmark (Den)	77.6	90	95.3	80	32.1
Japan (Jap)	73.6	70	94.3	60	67.2
Taiwan (Tai)	71.1	70	73	70	89.8
Euro Zone (EZ*)	70.4	70	83.6	72.5	47.2
Norway (Nor)	70.1	90	97	50	45.9
Korea (Kor)	68.6	70	83.1	70	81.5
Israel (Isr)	68.4	70	69.7	70	60
Mexico (Mex)	65.8	50	82.1	50	77.2
South Africa (SAf)	64.1	50	70.8	50	79.3
Kuwait (Kuw)	63.7	50	67.9	50	39.2
Peru (Per)	62.1	40	65.1	50	92.2
Brazil (Bra)	60.9	50	50.3	50	88.8
Fiji (Fij)	59.8	30	70.4	30	74.3
Saudi Arabia (SaA)	59.1	50	52.9	30	46.1
Philippines (Phi)	57.4	30	54.2	30	91.4
India (Ind)	55.6	50	49.6	40	89
Indonesia (Ido)	55.1	30	45.7	30	90.7
China (Chi)	54	20	54.9	30	88.6
Egypt (Egy)	53.2	40	39.9	50	73.6
Nigeria (Nig)	52.6	30	63.1	30	41.7
Venezuela (Ven)	47.7	30	48.8	20	69.5
Iran (Ira)	43.1	10	54.9	10	59.8
North Korea (NK)	3	10	0	10	0

* Computed as equally weighted average of the EZ members

Source: IEF 2007 [20]

The matrix model

The Matrix Model ([7], [8], [9]) is focused on “management” and “ownership” as relevant criteria characterising economic systems (Table 3). While the association private ownership and decentralised management is typical to the democratic and free-market countries (quarter I), the union centralised management - state ownership defines the command economy (quarter III) whose former centrally planned economies from Eastern Europe are the best representatives. Two more associations are shown: private ownership with centralised management (quarter II), defining the economy of monopoly, and state ownership with "decentralised management" (quarter IV), introducing the so-called "social-market” economy.

Table 3

The matrix model and the corresponding economic systems (Scarlat)

Criteria		Management criterion	
		Centralized	Decentralized
Ownership criterion	Private	II. Economy of monopoly	I. Free-market economy
	State	III. Economy of command	IV. Social-market economy

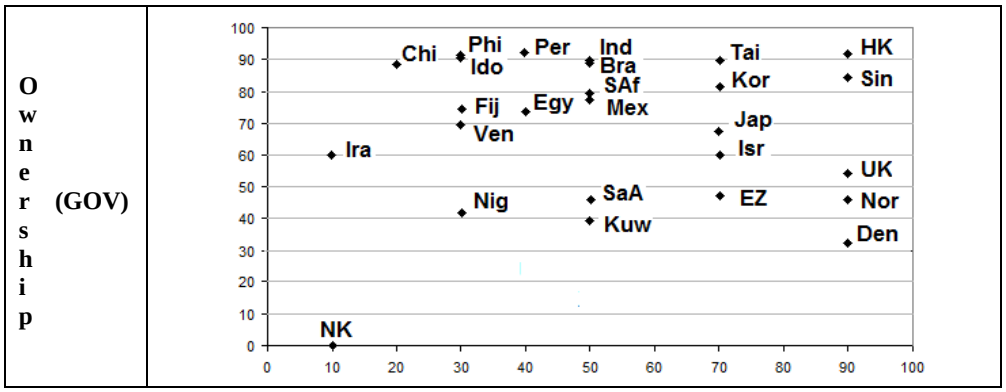
While the management criterion was already discussed, the ownership criterion is clearly reflected by the share of the state owned enterprises in GDP. It is well known that the government might exert its influence either via open market instruments (and thus behaving like any common player on the market according to the principle "the owner makes the decisions") or by using other intervention levers like taxes regulations, trade policy or property rights regime influencing the long term decisions of the economic agents whatever their size. The open market instruments are the most desirable channels a government can influence the economy. IEF is explicitly providing this factor named "government intervention in the economy". Therefore, GOV is the most suitable IEF factor that matches the ownership criterion.

Considering the criterion proposed for assessing the degree of management decentralization (Table 1) and by assigning scores from 1 (centralized management) to 5 (decentralized management) with integer quanta, one obtains the distribution presented in Figure 3b. Figure 3 shows the correspondence between the chaotic approach and PRR score when keeping the same ownership criterion (i.e. GOV). Noticeable differences are because of the various time scales of the two methods: the chaotic approach is extracting the basic features of centralization/decentralization from a 12 years long analysis while IEF is estimated for one year only.

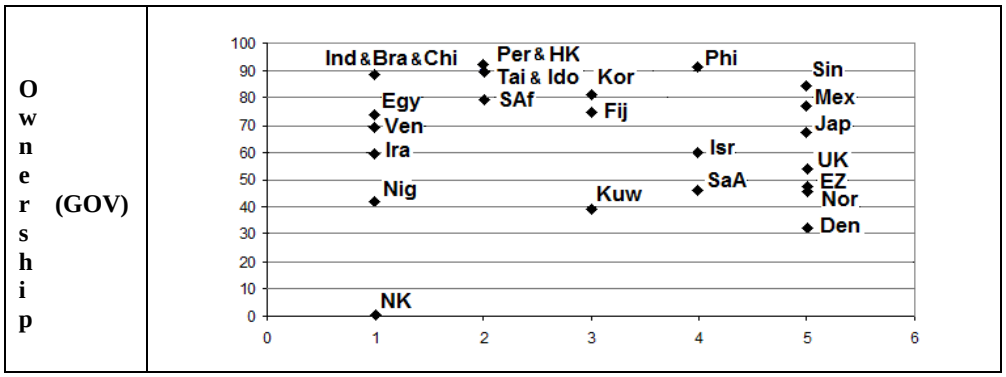
One could easily relate the matrix model and the IEF projection at least at their extremes: free-market economy with IEF tending to unitary value, and economy of command with IEF < 0.5 (repressed). By comparing Table 3 to Figures 3a and 3b, one can split the last ones in order to be formally identical with the matrix model (assuming that a proper delimitation is done). As example, a possible grouping is presented in Table 4. The critical point is where to settle the border between the categories. Whatever the choice, there will always be "in favor" and "against" arguments. However, it is important to notice that, for some practical reasons, a finer ranking is better than four-type taxonomy. On the other hand, identifying the main features of each category can be of top interest.

Exceptions from the rule are also expected.

China falls outside the economy of command quarter whatever the map 3a or 3b, due to its relative small share of state owned property. However, the economic performances of China are real and have more profound causes than the monopoly of the state could explain.



a. Management (PRR)



b. Management (chaotic approach)

Fig. 3. Economic systems distribution in matrix model coordinates

The 2-dimensional map is revealing a more detailed picture of the country distribution than the 1-dimensional aggregate IEF. One should remark that more than three quarters of the countries ranked in IEF have the aggregate score greater than 50% i.e. they are mostly free. This holds true also for the factors of economic freedom so that there is a higher density in the range 50% - 100% in Figure 3a. It is not the case for the chaotic approach where the criterion for management decentralization is spreading the representatives over the whole horizontal axis.

Anyway, all these cases are challenging subjects to further studies.

Table 4

A possible classification – based on the chaotic approach and matrix model

Type of		Management	
		Centralized	Decentralized
Ownership	Private	Taiwan South Africa Brazil China India Egypt Indonesia Fiji	Hong Kong Kuwait Saudi Arabia Peru
	State	Nigeria Venezuela Iran North Korea	Singapore United Kingdom Denmark Japan Norway Israel Korea Mexico Philippines Euro Zone

7. Conclusions

Economic systems can be analyzed and described using the concepts of econophysics (chaos theory / nonlinear analysis). The method developed by the authors – the persistence of strange attractors with respect to a trend removal procedure – offers a reliable criterion to assess the level of management decentralization in that economic system. Mathematically sophisticated, the analytical tool has solid scientific ground. The research results are consistent with:

- matrix economic model;
- ranking provided by the Index of the Economic Freedom – IEF;

PRR is the best IEF factor for characterizing the management decentralization while GOV is the most suitable IEF factor to assess the ownership.

The chaotic dynamics analysis applied in the case of 26 economic systems (25 countries worldwide plus Euro Zone), over a 12 years period (1 January 1996 - 31 December 2007), has led to the conclusion that five groups of economic systems can be identified – as far as their level of management decentralization.

The matrix model and investigation method theory of chaos-based are fully applicable not only to analyze the economic transition processes as well as their end but also to explore the managerial characteristics as the centralization/decentralization ratio of any specific macroeconomic system.

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APPENDIX

For a quasi-Dirac type signal of the same length with the time length of the series (4200 days) with a gap of 90 days (Fig. A1) the LSE approximating polynomial of 85 degree is shown in Fig. A2. The spectrum of the polynomial in double logarithmic scale is shown in Fig. A3. A detailed picture of its spectrum in linear coordinates for longer periods is given in Fig. A4. Since the period of 12 years is corresponding to the frequency N=1, it follows that the quarter is equivalent to N=48 day^{-1}.

However, one should notice that even de-trending is not equivalent with filtering; the periods longer than a quarter are significantly removed from the series. Fig. A4 depicts the attenuation with a factor of approximately ten of the quarterly period with respect to all the periods longer than six months or, equivalently, the frequency $N \leq 24$.

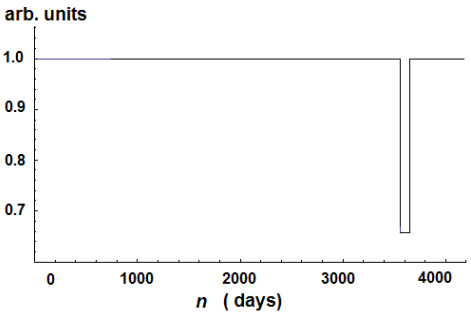

Fig. A1

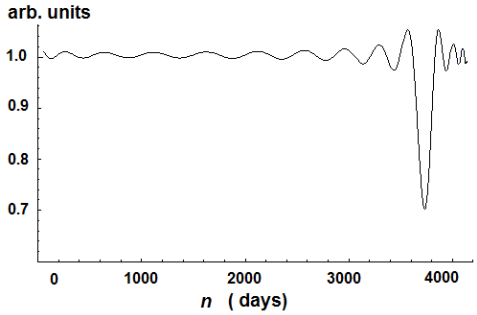

Fig. A2

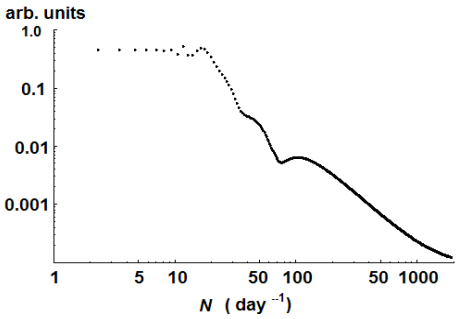

Fig. A3

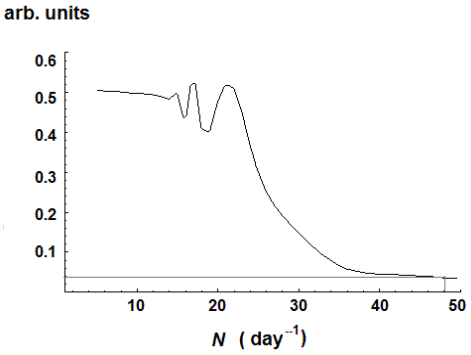

Fig. A4