sustainability

MDPI

Review

A Chaos Theory Perspective on International Migration

Anca Tănasie [1], Raluca Drăcea [1] and Georgiana Raluca Lădaru [2,*]

1 Faculty of Economics and Business Administration, University of Craiova, Craiova 200585, Romania; ancatanasie@gmx.de (A.T.); raluca.ladaru@eam.ase.ro (R.D.)
2 Faculty of Agrifood and Environmental Economics, The Bucharest University of Economic Studies, Mihail Moxa Street, no. 5-7, District 1, Bucharest 010374, Romania
* Correspondence: raluca.ladaru@eam.ase.ro

Received: 18 October 2017; Accepted: 11 December 2017; Published: 17 December 2017

Abstract: This paper aims at providing a different approach to international migration analysis, beyond classical models previously proposed by specialized literature. Chaos theory is getting more and more applied into macroeconomics once traditional linear models or even previous dynamic analysis become less suitable. Modern science sees chaos as unpredictable evolution, maybe even disorder. Still, chaos has got its own rules and can describe many dynamic phenomena within our world. Thus, we test whether international migration data falls under the rules of chaos and whether recent developments within the "European migration crisis" (the total daily migration inflows towards the coasts of Italy, by sea, from January 2014 to April 2017) could be described as chaotic.

Keywords: international migration; chaos theory; crisis; EU

1. Introduction

Given recent evolutions of the world economy and the clear failure of linear modeling in the field of economics, several other alternatives have been explored and tested, all of them in the area of non-linear dynamic systems. Chaos theory is one of them and this paper aims to employ this methodological approach in order to provide a new insight into international migration.

International migration has been a focal point of interest lately given the systemic changes on a global level. In modeling migration phenomena, there have been several approaches trying to simulate social mechanism from real life, population mobility majorly motivated by security and welfare reasons. Society's changes, evolution, economic development, but also political regimes and conflicts are driving international migration. "Migration is inextricably linked to development, the nexus is neither simple nor linear" [1]. This paper aims to work on a chaos algorithm suitable for modeling and describing the nonlinearity of the migration phenomena.

Such a quest into the potential chaotic evolution of international migration is motivated by the limits of previous research in the field, especially in the empirical analysis area, where specific limitations have been continuously pointed out in specialized literature.

The focus of the present research is an international migration analysis from a chaotic perspective. As socio-economic systems, especially highly complex ones, such as world economy and society, have already been classified as non-linear dynamic systems, such a new approach would provide a new perspective in assessing the evolution of international migration given recent global evolutions. Previous approaches involved either static assessments of migration, instead of dynamic, or optimization algorithms that most times were limited both in terms of accuracy, but also from a predictive potential point of view.

International migration is again a complex phenomenon, not just from a theoretical point of view, but also from an analytical one, at the point where one should establish a certain trend or forecast taking into account existing sets of variables, while this is, as chaos theories describe it, a very sensitive system to rather minor stimuli. Macroeconomics and social environments provide even further challenges here. Estimation power is even lower in this area as the global economic and social system is a complex one, with a very rapid dynamics and volatility, with rather short and noisy time series.

One of the major questions raised once switching from a classic linear approach of economic data series to a non-linear chaotic approach concerns the relevance of such a model. Is international migration in fact chaotic? Can we really distinguish between random shock effects and endogenous variations given the non-linear correlation between economic and/or social variables? The answer is not straight forward, as the clear separation between stochastic and deterministic data would provide a really important step forward, from both an analysis and a policy point of view—providing a strong basis for accurate economic, social, or political decision.

In this paper, we shall focus on migration flows incoming to the southern coast of Italy as this is the area mostly confronted with migrants arriving in Europe given political instability, war, poverty and other types of social and economic pressures. Most people arrive to Italy by sea and represent a serious humanitarian crisis in Africa—Morocco, Guinea, Nigeria, Cote d'Ivoire, Gambia, Senegal, Malim or Sierra Leone—and also Pakistan, Bangladesh, Syria, etc.

Migration towards the Italian shores is important from several points of view: first, Italy has been one of the main entry points into Europe through North Africa as Libyan shores are only 290 miles away, second, there has been a significant migration inflow increase that generated, according to a Corriere della Sera survey, an important popular negative impact and third, Italy has been seeking EU support for dealing with the migration crisis according to the Dublin Regulation. Consequently, such a situation raised not just humanitarian challenges but also financial, social, and political ones. Thus, we consider the Italian case to be relevant for such an analysis.

2. Literature Review

In terms of international migration, theoretical approaches have a wide range of variation. It all starts with the neoclassical model where the core motivation behind this phenomenon was in fact the maximization of an individual's utility as subject to budget constraints, and thus wages become the maximization factor [2,3].

Starting from the production factors' distribution where the high equilibrium wage is due to the gap between labor and capital [4], migration continues up to the point where the wage differential is actually covered by the cost of migrating from one region to another. However, this is just the beginning in evolution, determining factors and theoretical approach. Economic and social development brought several changes in all areas.

The basic utility function has been later developed including different other variables such as: the probability of acquiring a job [5], wage and production subsidies [6], capital mobility between rural and urban areas [7], or "endogenous determination" [8].

Research on human capital [9] changes the insight on migration towards the investment side—the migration decision is now based, according to age and region, on the value of expected return on the individual's skills. Once this theory has been developed, conclusions pointed towards high qualification of migrants and towards the fact that such migrants are by far not representative for the group of their origin, thus casting doubt upon the accuracy of research results obtained by using aggregate migration data.

Dynamic approaches on migration, such as family migration [10] or network migration [11], switched the focus from the factor-price differential, to the influence exercised by a downsize in risks given the networking mechanism and its role in providing information, developing opportunities and creating a self-perpetuating process.

Given the two main "sets of extant theory" of the "new paradigm of mobility" as approached by Sheller and Urry (2006) [2], the specific recent migration inflows into southern Europe, given their economic and social motivation (such as poverty, lack of safety, war, and political pressure), fall under a different category, rather in compliance with the "nomadic theory" that "celebrates the opposite of sedentarism".

Beyond strictly theoretical aspects, empirical studies deal with serious issues in terms of the data to be processed. For example, the existing time series containing migration data are of course not stationary as classically appropriate for standard econometrics. Thus, a combined analysis involving a stationary investigation doubled either by regression or an error correction model would be necessary, and even if long-term series would be available, which is not always the case, results would still have an average degree of accuracy.

According to Bauer and Zimmerman (1995) [12] "empirical studies using aggregate data have substantial problems in identifying the determinants of the migration decision", and the problems are rather in the vision area of the migration phenomenon as a whole.

Starting from these existing models and considering the need for progress in both theoretical/vision and data analysis, chaos theory and its applications might prove useful in assessing international migration, but also in correlating its evolution rather with receiving states' policies, than with labor market effects.

Nonlinearity aspects, as pointed out by Marcu and Bisci (2012) [13], have been occurring in several research area where complex system an evolutions are studied, including the economic one, thus, nonlinearity and dynamic systems will still be under the focus.

'Chaos' is a concept with ancient Greek origins, meaning, 'void', the moments prior to the creation of universe when existing laws were not even there. Modern science sees chaos as unpredictable evolution, maybe even disorder. Still chaos has got its own rules and can describe many dynamic phenomena within our world.

According to Ruelle (2001) [14] a chaotic system's first feature is "extreme sensitivity to its initial conditions" and the second one, according to James (2003) [15] is the existence of "complicated patterns of nonlinear relationships ... which are not truly random".

Within chaotic systems "minor experiences of single individuals can lead to unpredictable changes in the world", as it is the case of individual migrants issues—whether economic, social, or political—that generate a significant change in societies and economies on a regional and even global level.

3. Materials and Methods

The world around seems, at least apparently, to be made up of two types of systems—one category evolving and developing based on a deterministic set of rules, while the second one cannot be described using classic equations. Why the difference? Or might there in fact be no difference if these rules have not yet been discovered or if we are simply facing a random combination of deterministic and non-deterministic factors. Thus, chaos theory provided an alternative for the study of social and economic activity.

From an economic point of view, whenever un-forecasted disturbances occurred, there have been two main hypothesis: either that there are too many variables influencing that certain economic evolution to be incorporated in a deterministic model, or that there is an underlying trend blurred by white noise or random shocks that generate distortions.

For a long time, linearization has been used, starting from the assumption that analytical solutions would be obtained given the direct proportionality between variables' changes and the fact that limited input errors would provide limited projection errors [16]. That was not always the case for the economic system. Consequently, such a non-deterministic system was classified as complex or even chaotic. This is not the classic sense of the word, as behavior is not as random as it would appear.

The interesting aspect of chaos systems is that in modeling them we may start from the simplest non-linear equation where changes in variables determine extreme variations in results, thus not necessarily requiring complex equation systems. For the research area of some major economic phenomena and as part of the global or regional evolution, focusing on maybe one aspect of non-linearity is suitable. When augmenting in favor of non-linearity and a chaos approach, one of the main issues is the hypothesis of time continuity, which is not always the case, especially in terms of macroeconomic policy-making which is rather episodic and cannot support such an assumption. This is also the case for international migration, which could be rather episodic under certain circumstances. Still, the aim is to get simplified representations of a complex system within the used models, as very complex behavior patterns might have very simple causes. Chaos theory is very useful in this respect.

Chaos theory generally deals with "irregular behaviors in a complex system that are generated by nonlinear deterministic interactions with only a few degrees of freedom, where noise or intrinsic randomness does not play an important role" [17].

Chaotic systems just seem unpredictable as they present themselves with a high number of variables providing un-proportional results in comparison with the changes induced, but are in fact deterministic. The socio-economic system may seem to be a chaotic system involving a huge number of influencing factors. Deterministic chaos is thus the chaos in highly complex systems. Deterministic chaos does not automatically mean total predictability, but at least it improves predictive power and it enables short-term decisional process.

The chaotic approach provides the opportunity to accurately forecast potential future outcomes, compared to stochastic trajectories that cannot be projected into future. Even though, economic chaos is still an important research issue [18].

From a methodological point of view, in macroeconomic analysis, given the noise of data series, the Lyapunov exponent, BDS test, and correlation dimension are the widest used instruments.

The correlation dimension measures the dimension of a so-called "strange attractor" [6], but its major drawback is the simplicity of the calculation. Consequently, it does not provide enough relevant results for the chaos classification.

The Lyapunov exponent methodology is generally suitable for data series containing a large number of observations as to be able to provide accurate results.

The Brock, Dechert, and Scheinkman instrument tests the restrictive null hypothesis that the series is independent and identically distributed [19]. Given the focus of our research—international migration—the Lyapunov exponent of a dynamical system—the quantity that characterizes the rate of separation of infinitesimally close trajectories, is the appropriate instrument when aiming to estimate and perhaps even forecast for short time intervals the evolution of such a phenomenon within the EU.

Even under these deterministic circumstances, chaos is unpredictable except for short periods of time. According to Frison & Abarbanel (1997) [1], the approximate time limit that can get accurate predictions for a chaotic system is a function of the largest Lyapunov exponent.

$$\Delta t_{max} = \frac{1}{\lambda_{max}} \tag{1}$$

From a methodological point of view, we consider two neighboring points—$\chi_1(0)$ and $\chi_2(0)$—at the moment $t = 0$, as starting points for two space trajectories. These are the international migration trajectories to be analyzed and placed or not within the chaotic data features. *d(0)* denotes the distance between these two points. As these points migrate along this trajectory from moment $t = 0$ to moment t, the new distance will be denoted *d(t)* and measured again.

$$\frac{d(0)}{d(t)} = e^{\chi t} \tag{2}$$

The Lyapunov characteristic exponent is χ when $t \to \infty$.

When $\chi > 0$, the two trajectories diverge exponentially, the Lyapunov characteristic exponent measuring the divergence rate of the system [19].

The dynamic system may be thus assed by means of the Lyapunov exponent, aiming to get an insight of its true nature. As the coefficient increases in value, the stability of the system increases, thus dragging data further away from chaotic distribution towards regular deterministic dynamic systems. $\lambda \rightarrow -\infty$ shows a super-stable system.

According to previous chaos theory and studies [20], λ could take the following values:

If $\lambda < 0$ the system generates a stable fixed point or a stable periodic trajectory, the system is non-conservative;
If $\lambda = 0$ the system is conservative;
If $\lambda > 0$ the system in chaotic and unstable.

In order to measure the gap between the two trajectories, we compute the maximal Lyapunov exponent

$$\lambda = \lim_{t \to \infty} \lim_{d(0) \to 0} \frac{1}{t} \ln \frac{d(t)}{d(0)} \tag{3}$$

We use the Lyapunov exponent to measure the gap between trajectories, where x_0 and $x_0 + \varepsilon$ are the two neighboring points, we have the following equality [20]

$$\varepsilon e^{n\lambda(x_0)} = |f^n(x_0 + \varepsilon) - f^n(x_0)| \tag{4}$$

Thus, extracting the Lyapunov exponent and applying the limit, we get

$$\lambda(x_0) = \lim_{n \to \infty} \lim_{n \to 0} \frac{1}{n} \ln \left| \frac{f^n(x_0 + \varepsilon) - f^n(x_0)}{\varepsilon} \right| = \lim_{n \to \infty} \frac{1}{n} \ln \left| \frac{df^n(x_0)}{dx} \right| \tag{5}$$

as

$$x_i = f^i(x_0) \tag{6}$$

and

$$f^n(x_0) = f\left(f^{n-1}(x_0)\right) \tag{7}$$

(5) becomes

$$\frac{df^n(x_0)}{dx} = \grave{f}(x_{n-1})\grave{f}(x_{n-2}) \ldots \grave{f}(x_1)\grave{f}(x_0) \tag{8}$$

and the Lyapunov exponent becomes

$$\lambda(x_0) = \lim_{n \to \infty} \frac{1}{n} \sum_{1=0}^{n-1} \ln \left| \grave{f}(x_i) \right| \tag{9}$$

According to Jimenez (2002) [21], we define Y1, Y2, ..., Yr, the daily data belonging to our time series and dmax as "the maximum distance between two points of the series to be considered as infinitesimally close", where

$$d_K = \left| d_{j+k} - d_{i+k} \right| \tag{10}$$

and

$$d_0 = \left| d_j - d_i \right|, \; d_0 \leq d_{max} \tag{11}$$

At this point, main issues concern the time span while reaching the position from one point to another, the length of the time series, the total duration, the initial conditions, etc. Generally, the initial distance between the two points can be considered according to Jimenez (2002) [21] as the initial status of the system. As this distance can be maintained according to Hilborn (1994) [22] and Theiler (1986) [23], auto-correlation time is

$$\tau = \frac{1}{ln\ (1/\rho)} \tag{12}$$

if $\rho- > 1$, then,

$$\tau = \frac{1}{1 - |\rho|} \tag{13}$$

Furthermore, Dimmig and Mitschke (1993) provide means for the computing of the "number of initial conditions required for characterizing the attractor according to Lyapunov's maximum exponent" [24]. Such an N has been suggested according to Wolf (1985) to be between 10 and 30 [25]. Of course, values may be subject to variation.

$$N = \left(\frac{\sqrt{d_c}}{d_{max}}\right)^{d_e} \tag{14}$$

The Lyapunov coefficient is then computed for the series and the average is Jimenez (2002) [21]

$$\lambda = \frac{1}{N}\sum_{i=1}^{N} \lambda_{d_0} \tag{15}$$

This chaos methodology based on the Lyapunov coefficient has been applied for daily data series of all incoming migrants to the Italian shores, by sea—January 2014 to April 2017 provided by the United Nation Commission for Human Rights (UNHCR)—The UN Refugee Agency. Thus, we sum up over 1000 observations, a series length that could provide quite accurate results.

4. Results

The presented methodology has been applied using statistical data concerning migration towards Italy's shores during the critical period with major inflows coming from Syria, Afghanistan, Pakistan, etc. Data have been processed using MATLAB toolbox.

From a methodological point of view, when assessing the Lyapunov exponent, the first issue raised would be the correct lag. That would be the lag before of first decline of autocorrelation value below $\exp(-1) = 0.367879441$ [26]. In case of such data where nonlinear dependency autocorrelation, mutual information criteria will be used for selecting correct lag value. If both criteria—autocorrelation—and mutual information fail to select tau, tau = 1 is selected automatically.

The second issue would be the proper value of embedding dimension. Depending on the noise of the data set, False Nearest Neighbors method or the symplectic geometry method may be used in order to generate the appropriate embedding dimension. Implicit zero value for the embedding dimension can only be used in case there is no suitable information concerning such a value and the noise level is rather low as to allow FNN methodology.

Figure 1 illustrates the data series used as part of our methodology—the migration inflow by sea towards Italy's coast—over 1000 observations.

According to the chart distribution, the data is of course non-linear but the degree of stability of this system remains to be established, as MATLAB data processing provides a general insight on the same conclusion whether chaos may apply to at least recent migration patterns towards Europe. Motivation for such inflows has switched from the income differential to safety and political aspects such as the Syrian civil war, the Bashar al-Assad regime, and ISIS threat and combat.

Beyond Syrian refugees, migrating populations include Pakistan, Morocco, Guinea, Nigeria, Bangladesh, Cote d'Ivoire, Gambia, Senegal, Mali, or Sierra Leone. The choice in favor of migration inflows towards Italy has mostly been representative. Being an EU border area, with perhaps the highest influx of migrants within the Mediterranean area, Italy represents good extrapolation basis for the whole EU. Testing provides proof of a rather stable system with an average Lyapunov coefficient $\lambda = -5.550684208129385 \times 10^{-2}$ non-conservative, with a stable periodic trajectory.

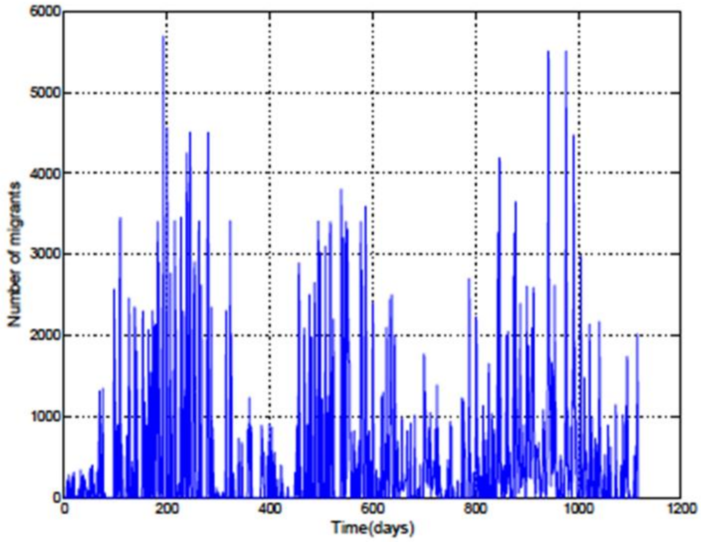

Figure 1. Sea arrivals by day—Italy (2014–2017). Source: authors' computing based on UNHCR—UN Refugee Agency data retrieved from: https://data2.unhcr.org/en/situations/mediterranean/location/5205.

This stable periodic trajectory may be determined by the high frequency of observation during a rather narrow time interval, as the integration phenomenon is concerned. The considered time interval being the very peak of the EU migrant crisis, while the over-all historic trend would of course be characterized by an increased instability. Once extended, the time frame would perhaps generate such instability given inconstant inflows of migrants from different areas of the world. This should of course be considered stable for the given migration episode considered here.

Another cause for the system's stability could be the fact that we have analyzed migration by sea towards the EU and there is a strict correlation between incoming flows and seasonal access to sea transport and also weather conditions given the fact that war refugees are a special category of migrants whose choice is based not on the wage differential, whose journey is under a life-and-death threat and who most of the time use improvised and crowded means of sea transport.

For the studied case, we have embedded a one-dimensional series into a multidimensional space. Figure 2 shows the evolution of the Lyapunov exponent versus time. Over time, variation in the Lyapunov coefficient finally depicts a rather stable system when talking about migrating inflows towards the EU.

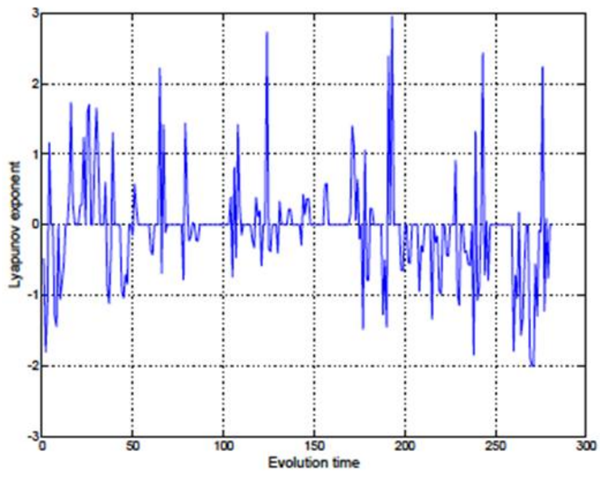

Figure 2. Evolution of the largest Lyapunov coefficient over time (2014–2017 split into 40-day time intervals). Source: authors' computing.

5. Discussion

Present findings point into the direction of modeling international migration according to new rules, as new circumstances would require. Starting from the very determinants of migration, from the previously proven hypothesis that migration as a phenomenon is far from falling under the deterministic models' framework, we have taken it into a new methodological area. Chaotic systems' methodology is rather useful in determining the stability degree and predictability of maybe an episodic event within a very complex system—the European economic and social environment.

One could have also expected such a system to become rather unstable given the multitude of variables influencing directly or indirectly migration and through that the whole European system, but MATLAB computing of existing data has proved a certain degree of stability, meaning that effects have not rendered the system completely chaotic.

By difference to existing research, we get the simplified pattern of a rather complex system, in dynamics, considering some very simple causes at its basis, such as war, political instability, poverty, social insecurity, through a non-linear model. In this case, migration evolution is a trajectory evolving within infinitesimal separation the rates. Furthermore, such methodology application could result in an insight into future developments and potential policy measure responses accurately designed as such.

6. Conclusions

Recent migration inflows into the southern coast of Italy, from a sociological point of view, rather fall under the classical migration theories based on safety and economic triggers, but into an environment where development has determined a new insight into human mobility once the new century provided new variables of time, space, technology, communication, or transport for an ancient phenomena—migration.

Political instability and poverty in areas—such as Syria, Afghanistan, Pakistan, or even Northern Africa—have caused significant population moves, unprecedented in recent modern European history. This also raised aery interesting research questions that we have tried to answer using chaos theory methodological approach.

After analyzing the daily data series provided by the United Nation Commission for Human Rights (UNHCR)—The UN Refugee Agency (2014–2017), results indicate the presence of chaos that is essential when wishing to forecast and accurately predict such a phenomenon for a medium or long term time horizon.

Our analysis points out that beyond the non-linearity of the international migration phenomenon, the chaos approach could represent an interesting approach capable of modeling and describing short-term evolution but also creating perspectives for future estimates. The Italian case has been representative for recent developments within the EU and thus, using such an example, we could provide new research prospects.

Further on, developments of such a study [27–30] could also provide the most suitable model describing this side of international migration and other controversial aspects having totally different evolutions, features, and motivation than other modern migration inflows previously analyzed. Europe is now different, as it is the case for the whole world from both a socio-economic but also political perspective. International conflicts and political regimes have a totally new dimension and impact on global population movement, and beyond locating motivation future migration, estimations should also take into account both intensity of the phenomena and optimal non-linear modelling.

Concluding, recent migration inflows coming from Northern Africa, Syria, Bangladesh, etc.—when considered from the perspective of the chaos theory—can be considered a rather stable system under the rules of chaos.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Frison, T.; Abarbanel, H. Ocean gravity waves: A nonlinear analysis of observations. *J. Geophys. Res. Oceans* **1997**, *102*, 1051–1059. [CrossRef]
2. Sheller, M.; Urry, J. The New Mobilities Paradigm. *Environ. Plan.* **2006**, *38*, 207–226.
3. Ravenstein, E.G. The Laws of Migration. *J. R. Stat. Soc.* **1889**, *52*, 241–305. [CrossRef]
4. Cristea, M.; Dracea, R.; Marcu, N. The drection of the financial sector's involvemnt in overcoming crisi: A case study of Romania. *Afr. J. Bus. Manag.* **2010**, *4*, 3356.
5. Harris, J.; Todaro, M. Migration, Unemployment, and Development: A Two-Sector Analysis. *Am. Econ. Rev.* **1970**, *60*, 126–142.
6. Bhagwati, J.; Srinivasan, T. On reanalyzing the Harris-Todaro model: Policy rankings in the case of sector-specific sticky wages. *Am. Econ. Rev.* **1974**, *64*, 502–508.
7. Corden, W.M.; Findlay, R. Urban Unemployment, Intersectoral Capital Mobility and Development Policy. *Economica* **1975**, *42*, 59–78. [CrossRef]
8. Stiglitz, J.E. On the Irrelevance of Corporate Financial Policy. *Am. Econ. Rev.* **1974**, *64*, 851–866.
9. Sjaastad, L. The costs and returns of human migration. *J. Political Econ.* **1962**, *70*, 80–93. [CrossRef]
10. Mincer, J. Family migration decisions. *J. Political Econ.* **1978**, *86*, 749–773. [CrossRef]
11. Massey, R.G.; Espana, F. The social process of international migration. *Science* **1987**, *237*, 733–738. [CrossRef] [PubMed]
12. Bauer, T.; Zimmerman, K. 1998, Causes of international migration: A survey. In *Crossing Borders: Regional and Urban Perspectives on International Migration*; IZA Discussion Paper No., 170; Gorter, C., Nijkamp, P., Eds.; Ashgate: Brookfield, VT, USA, 2000; pp. 95–127.
13. Marcu, N.; Molica Bisci, G. Existence and Multiplicity of Solutions for Nonlinear Discrete Inclusions. *Electron. J. Differ. Equ.* **2012**, *192*, 1–13.
14. Ruelle, D. *Raslantı ve Kaos*; Tubitak Press: Ankara, Turkey, 2001.
15. James, F. Comment on Exact solutions to chaotic and stochastic systems. *Chaos: Int. J. Nonlinear Sci.* **2003**, *13*, 123. [CrossRef]
16. Buse, L.; Siminica, M.; Circiumaru, D.; Marcu, N. *Corporate Economic and Financial Analysis*; Sitech Publishing House: Craiova, Romania, 2007; pp. 35–38.
17. Gao, J.; Hu, J.; Tung, W.-W. Facilitating Joint Chaos and Fractal Analysis of Biosignals through Nonlinear Adaptive Filtering. *PLoS ONE* **2011**, *6*, E24331. [CrossRef] [PubMed]
18. Barnett, W.; Chen, A.P. Deterministic Chaotic and Fractal Attractors as Tools for Nonparametric Dynamical Econometric Inference: With an Applications to Divisia Monetary Aggregates. *Math. Comput. Modeling* **1988**, *10*, 275–296. [CrossRef]
19. Brock, W.A.; Dechert, W.D.; Scheinkman, J. A Test for Independence Based on the Correlation Dimension. *Econ. Rev.* **1996**, *15*, 197–235. [CrossRef]
20. Ciobanu, D. The Horizon of Prediction for Exchange Rate EUR-LEU. *Ann. Univ. Petroşani Econ.* **2012**, *12*, 85–92.
21. Jimenez, A.M.; Vara De Rey, C.; Torres, A.R. Effect of Parameter Calculation in Direct Estimation of the Lyapunov Exponent in Short Time Series. *Discret. Dyn. Nat. Soc.* **2002**, *7*, 41–52. [CrossRef]
22. Hilborn, R.C. *Chaos and Nonlinear Dynamics. An Introduction for Scientists and Engineers*; Oxford University Press: New York, NY, USA, 1994.
23. Theiler, J. Spurious dimension from correlation algorithms applied to limited time-series data. *Phys. Rev. A* **1986**, *34*, 2427–2432. [CrossRef]
24. Dimmig, M.; Mitschke, F. Estimation of Lyapunov exponents from time series: The stochastic case. *Phys. Lett. A* **1993**, *178*, 385–394. [CrossRef]
25. Wolf, A.; Swift, J.B.; Swinney, H.L.; Vastano, J.A. Determining Lyapunov exponents from time series. *Phys. D Nonlinear Phenom.* **1985**, *16*, 285–317. [CrossRef]
26. Shapour, M. *LYAPROSEN: MATLAB Function to Calculate Lyapunov Exponent*; University of Tehran: Tehran, Iran, 2009.
27. Subic, J.; Vasiljevic, Z.; Andrei, J. The impact of FDI on the European economic development in the context of diversification of capital flows. In Proceedings of the 14th International Business Information Management Association, Business Transformation through Innovation and Knowledge Management: An Academic Perspective, Istanbul, Turkey, 23–24 January 2010; Volumes 1–4, pp. 779–787.

28. Radulescu, I.G.; Panait, M.; Voica, C. BRICS countries challenge to the world economy new trends. *Proced. Econ. Financ.* **2017**, *8*, 605–613. [CrossRef]
29. Sima, V.; Georgiana, G.I. Labour market trends in România in the context of green economy. Available online: http://www.utgjiu.ro/revista/ec/pdf/2014-04.Special/22_Sima,%20Gheorghe.pdf (accessed on 9 December 2017).
30. Anghelache, C.; Anghel, M.G.; Panait, M. Main Developments and Perspectives of the European Union. *Roman. Stat. Rev.* **2017**, *2*, 57–79.