Chaos, Solitons and Fractals 110 (2018) 82–94

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

Recurrence quantification analysis of business cycles

Giuseppe Orlando [a,b,*], Giovanna Zimatore [c]

[a] Department of Economics and Finance, Università degli Studi di Bari "Aldo Moro", Via C. Rosalba 53, Bari, I-70124 Italy
[b] School of Science and Technologies, Università degli Studi di Camerino, Madonna delle Carceri 9, Camerino, I-62032 Italy
[c] CNR-IDASC, Institute of Acoustics and Sensors "O. M. Corbino", Via del Fosso del Cavaliere 100, Roma, I-00133 Italy

ARTICLE INFO

Article history:
Received 6 January 2018
Revised 26 February 2018
Accepted 26 February 2018

JEL Classification:
C61
E32
E37

2010 MSC 62P20:
65P20
70K75
91B55

Keywords:
Determinism
Numerical chaos
Economic dynamics
Business fluctuations
Cycles

ABSTRACT

This paper investigates, by means of recurrence quantification analysis, the characteristics of trade cycles and economic development. Trade cycles are complex phenomena oscillating because of economic downturns and expansions. In this paper the features of the underlying dynamics are studied over an extensive dataset e.g. Levy and Chen, OECD, BEA, etc. It is shown that recurrence quantification analysis can be suitably applied to economics and, therefore, may help in anticipating transitions from laminar (i.e. regular) to turbulent (i.e. chaotic) phases such as USA GDP in 1949, 1953, etc. Moreover, recurrence quantification analysis detects differences between macroeconomic variables, and highlights hidden features of economic dynamics.

1. Introduction

Burns and Mitchell [12] define business cycles as a type of fluctuation which "consists of expansions occurring at about the same time in many economic activities, followed by similarly general recessions, contractions, and revivals which merge into the expansion phase of the next cycle". Imperfections may be intended as those perturbations of the equilibrium that can lead to recessions or to expansions.

Recurrence is defined as the ability of a dynamical system to return to the proximity of the initial point in phase space, and recurrence quantification analysis (RQA) was developed in order to understand the behaviour of the phase space trajectory of dynamical systems.

There is a debate in the literature whether economy is chaotic or stochastic and whether shocks are endogenous or exogenous. Most studies concentrated on financial time series (e.g. stock indices) because of accessibility of data, frequency and length. The current work, with an extensive analysis on macroeconomic data (i.e. consumption, investment, capital and income), aims to investigate: i. The applications of recurrence plots (RPs), and their quantitative description provided by RQA, to dynamical regimes of business time series, ii. Whether RQA can give some indications on the nature of trade cycles as well as on the nature of macroeconomic variables and the economy.

The rest of the paper is organized as follows. The first Section is a brief review of the literature on business cycles, recurrence quantification analysis and its applications to economics and finance. The second Section features material and methods and includes the description of both the dataset and the RQA methodology. The third Section shows the analysis performed and the results obtained. The final section draws some conclusions and makes suggestions for future research.

* Corresponding author at: Department of Economics and Finance, Università degli Studi di Bari "Aldo Moro", Via C. Rosalba 53, Bari, I-70124 Italy
E-mail addresses: giuseppe.orlando@uniba.it, giuseppe.orlando@unicam.it (G. Orlando), giovanna.zimatore@uniroma1.it (G. Zimatore).

https://doi.org/10.1016/j.chaos.2018.02.032
0960-0779/

2. Literature review

RQA applications to economics and finance are not widespread and started later than in other fields [14,18,32,44,66]. The interest in RQA by economists stemmed from the world financial crisis of 2007–2010 which was not anticipated by a large part of economic literature [34]. In fact, the majority of economists, basing their models on standard equilibrium, implicitly assumed that "economies are inherently stable and that they only temporarily get off track" Colander et al. [16]. Moreover, the paradigm of the rational representative agent, "largely ignored" [16] the risk of new financial products and of the interconnections of markets. Therefore RQA applied to economics was seen as a potential "tool for the revealing, monitoring, analysing and precursoring of financial bubbles, crises and crashes" Piskun and Piskun [53]. Fabretti and Ausloos [23] found examples of financial markets in which RQA could detect a difference in state and recognize the critical regime such that a warning before a crash (in their case 3 months in advance) can be given. Along these line Addo et al. [2], looking for signals anticipating financial crisis, claim "the usefulness of recurrence plots in identifying, dating and explaining financial bubbles and crisis"; the findings from the data analysis with recurrence plots show "that these plots are robust to extreme values, non stationarity and to the sample; are replicable and transparent; are adaptive to different time series and finally, can provide better chronology of financial cycles since it avoids revision of crisis dates through time". Strozzi et al. [59], studying the Nordic Spot Electricity Market Data, confirm that determinism and laminarity detect "changes more clearly than standard deviation and then they provide an alternative measure of volatility". Moloney et al. [44], whilst investigating arbitrage-free parity theory for the Credit Default Swaps (CDS) and bond markets, questioned the assumption of a stable equilibrium "which is central to the arbitrage-free parity theory". In addition they found evidence of deterministic structures in the data and that "market is being trapped at certain levels" where "equivalence being trapped for a period of time is a characteristic of a nonlinear system (not a periodic or a random system)".

However, from a purely theoretical point of view, it is worth noting that the ability of RQA to predict catastrophic changes is in line with the fact that RQA is based upon the change in correlation structure of the observed phenomenon that is known to precede the actual event in many different systems ranging from physiology and genetics to economics. Gorban et al. [27] studied the behaviour of systems approaching a critical transition by many experiments and observations of groups of humans, mice, trees, grassy plants, and financial time series. They observed that even before obvious symptoms of crisis appear, correlation increases, and, at the same time, variance (and volatility) increases too. More specifically, with regard to finance, their case study of the thirty largest companies from the UK stock market within the period 2006–2008 supports the hypothesis of increasing correlations during a crisis and, therefore, that correlation (or equivalently determinism) increases when the market goes down (or correspondingly decreases when it recovers). Along this line Orlando and Zimatore [50] defined the so called RQE correlation index and they have shown, on a test signal, that it is able to detect regimes' changes. Moreover, by computing the RQE correlation index on USA GDP data [47], they have found that it may help in anticipating recessions.

3. Material and methods

The variables under investigation are Capital (K), Consumption (C), Investment (I) and Income (Y) (see Appendix A). Cyclical swings of an economy, Fig. 1, are typically analysed in terms of the duration or the amplitude between a peak and the succeeding trough [11]. The Peak-Trough-Peak (PTP) cycle can be caused by various factors such as negative shocks in demand, in supply, in price and in credit (i.e. when "financial distress produces sharp discontinuities in flows of funds and spending and when the financial strains include tight monetary policy, much lessened availability of money and credit, sharp rises of interest rates, and deteriorating balance sheets for households, businesses, and financial institutions") [21]. A prolonged and deep recession is called a depression.

In order to study business cycles and recessions, Fig. 2, from the point of view of a phase transition of non-linear phenomena, we applied RQA to time series extracted from different sources because we wanted to have an extensive set of data, with the highest number of points possible, covering the following dimensions: countries with different development paths (OECD A.3, BEA A.1), differences in methods for computing capital (M1, M2 A.2), gross versus net (Levy and Chen A.2), etc. A further requirement was that, whenever possible, the number of time series should be balanced across variable or dimension.

3.1. Business cycle, imperfections and controls

The identification of the root cause of economic fluctuations varies between different schools of thought. The Keynesian/post-Keynesian view is that, due to aggregate demand, the economy is inherently unstable (an endogenous imperfect system) therefore it can reach levels below or above full employment unless appropriately governed. This interpretation created a lively debate among econometricians such as Timbergen [61,62] and Frisch [26], who maintained that the economy is intrinsically stable and cycles are the effect of exogenous shocks. In particular Timbergen, following [69,57], described the "economy as a system of stochastically disturbed difference equations, the parameters of which could be estimated from actual time series" [39]. Similarly, according to Frisch, cycles are the effect of delays in new capital spurred by increased consumer demand. This causes recurrent but temporary oscillations in output absorbed in two or three cycles. Schumpeter identified in innovation and creative destruction those factors that cause the economy to deviate from Walrasian equilibrium: "capitalism is by nature a form or method of economic change and not only never is but never can be stationary" [56]. In this context "imperfections" must be intended as those perturbations of the equilibrium that lead to booms because of high profits made by frontrunners. This ends when more and more entrepreneurs copy the strategy of the pioneer firms and, therefore, the greater competition depresses margins up to the point of forcing foreclosures. At this point a depression starts and the market is cleaned of unprofitable firms. This equilibrium is maintained until the point at which technological or other innovations lay down the basis for another expansion. Phelps [52] and Lucas [38] explain business cycles on the grounds of incomplete information given that "key economic decisions on pricing, investment or production are often made on the basis of incomplete knowledge of constantly changing aggregate economic conditions. As a result, decisions tend to respond slowly to changes in economic fundamentals, and small or temporary economic shocks may have large and long-lasting effects on macroeconomic aggregates" [30]. The Austrian school [63,22] claims that a sustained period of low interest rates leads to excessive credit creation and then to an unstable imbalance between saving and investment. The recession (or "credit crunch") is caused by the need to re-establish the said equilibrium. In other terms, monetary shocks influence "relative prices, such as the term structure of interest rates, systematically altering profit rates across economic sectors. Resource use responds to those changes, generating a cyclical pattern of real income. The divergence of the interest rate structure, from the previous and unchanged time prefer-