Exploring the Chaotic Nature of COVID-19 Pandemic: Limit Cycles and Time-Lag Around the World

Yiannis Dimotikalis and Christos H. Skiadas

Abstract In this work the Chaotic Nature of the Covid-19 Pandemic data is explored. The Total Deaths (/million) to Total Cases (% population) of Covid-19 data from https://ourworldindata.org/coronavirus website are studied. Large 28 day-delays lead to characteristic Limit Cycles while the lag between applied and adopted measures tend to form characteristic limit cycle forms. A 28-day Moving Average was tested. The data period is from January 2020 to 23 November 2021. The time period is divided to Parts based on chart data curve. Similarities but also differences are present leading to group countries accordingly. An important issue is to explore the Covid-19 spread due to variations of the virus while the vaccine measures expand considerably.

Keywords Covid-19 pandemic · Limit cycles · Chaos · Data sets · Moving average · Health state · Nonlinear analysis

1 Theory and Applications

Covid-19 pandemic and several variations of the virus passed in a new era after the introduction of several vaccines adopted. Socioeconomic, political and demographic issues influence the spread of the virus and the vaccine adoption in all countries of the World. It was clear from the beginning that the thread was very serious and radical actions should apply. The spread of the disease followed an Exponential like growth. Without adopting immediate measures the health systems would collapse. In the first period radical actions were adopted at least to reduce the speed of epidemics while waiting for the appropriate vaccine invention and perhaps new drugs or treatment methodologies.

Y. Dimotikalis
Department of Management Science and Technology, Hellenic Mediterranean University, Agios Nikolaos, Crete, Greece

C. H. Skiadas (✉)
ManLab, Technical University of Crete, Chania, Crete, Greece
e-mail: skiadas@cmsim.net

C. H. Skiadas and Y. Dimotikalis (eds.), *14th Chaotic Modeling and Simulation International Conference*, Springer Proceedings in Complexity,
https://doi.org/10.1007/978-3-030-96964-6_9

For the first time in human history our national and international systems to collect, store and analyze datasets are so-advanced. However, the analysis of so-many datasets came to be a puzzle difficult to solve. The task was to reduce the growth speed of epidemics; but how fast and what measures where the most appropriate. At least to save the socioeconomic and political system while improving the health systems as well. Now, after almost 22 months after covid-19 invasion, we have enough experience from fighting the pandemic. However, the lessons learned in the first Covid-19 period before the vaccine introduction are not enough to handle the new situation.

Some lessons of the analysis from non-linear systems theory and the related chaotic behavior may be useful (see [1–3]). Chaos or chaotic attractors appear when "Time Delays" are present. It means that as long as a delay between treatment and cure appear chaos is present. Even more longer delays appear from local Authorities measures and interventions.

Governments tend to propose measures and correct again and again after collecting appropriate data. This could act like to try to correct the Stock Exchange fluctuations by many repeated actions. The best, in this case, is to carefully study the selected actions to be effective and designed for a large time horizon. The examples presented here for several countries while the same methodology for the other countries included by introducing data from https://ourworldindata.org/coronavirus.

2 The Data and the Limit Cycles

The data are collected and stored daily for almost all World countries. Of particular interest for our study are the new death data per day. The first step of the data handling was done from the website people by smoothing to reduce the particular differences from the daily data collection. The provided Covid-19 daily data for Greece are illustrated with yellow line in the next figure. However, this smoothing is not relatively adequate to keep the important part of the virus spread by excluding parts that form local changes. Radical smoothing is done with a 28-day transformation by taking into account 14 days before and 14 days after a particular date that a ± 14 days or 28 days smoothing. This is presented by the thick blue curve in the next figure. By this transformation smoothness is clear. Of course small details are missing but the appropriate data for providing the main limit cycles remain. The ± 14-day smoothing is in accordance with the 14-day quarantine suggested for Covid-19 infected people. For a detailed Moving Average theory and applications see [4]. The method we select is also termed as Central Two-Sided Moving Average around a day x with a $\pm\, k$-day summation around the point x. Accordingly the total space is $S = 2\ k\ +\ 1$ that is equal to 29 for the $k = 14$ case (Fig. 1).

Limit cycles are formed from the First difference (first derivative) of new deaths versus the new deaths per day. Of course the first derivative data is provided after a 28-day smoothing (± 14) as was done for the daily data. See next figure where

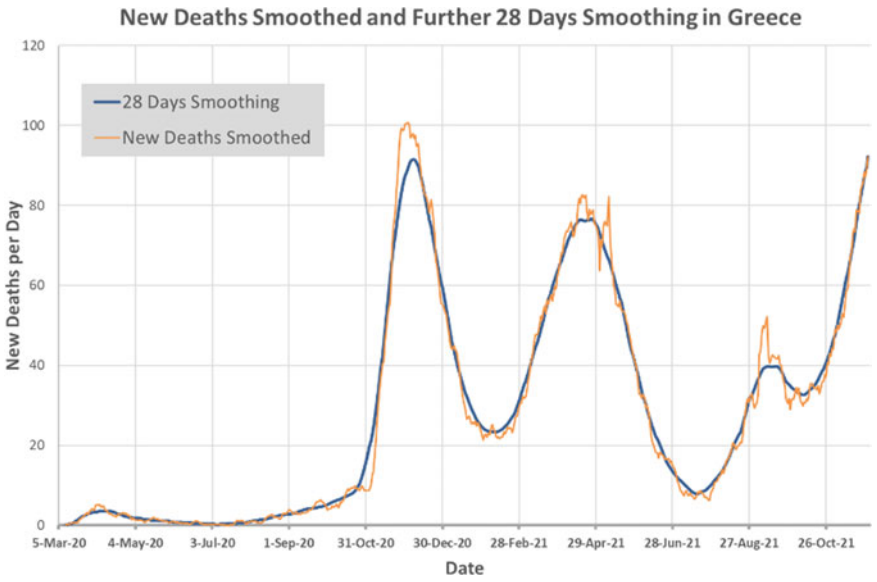

Fig. 1 Greece Covid19 data, new deaths smoothed

the data without smoothing are provided with orange whereas the blue curve is the 28-day smoothed one (Fig. 2).

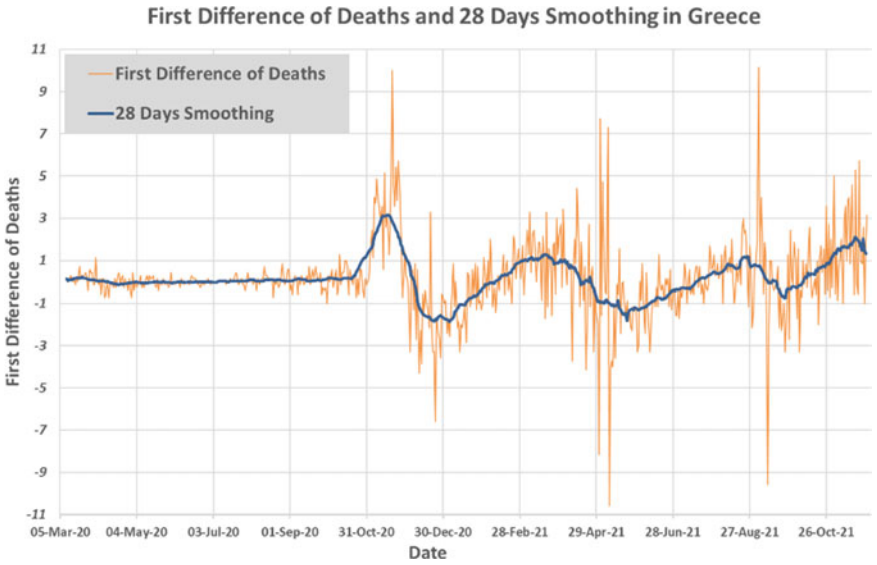

Fig. 2 Greece Covid19 data, first difference of deaths smoothed

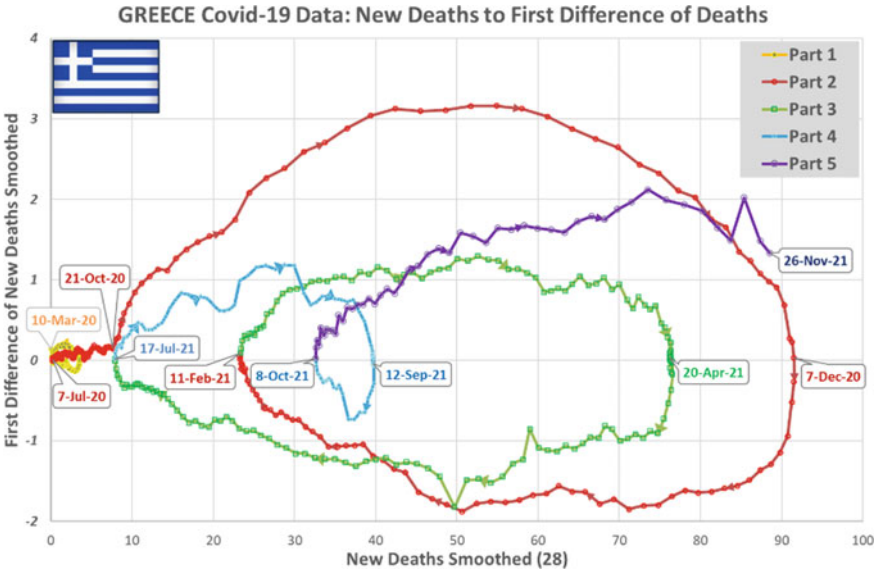

Fig. 3 Greece Covid19 data, new deaths to first difference of deaths

The chaotic like behavior is presented in the next figure for GREECE. X-Axis is for new deaths and Y-Axis represents the first difference of deaths. The 1st Part (yellow) is followed by the 2nd Part (red) and the 3rd Part (green). The final Part (cyan) is like a continuation of the 1st Part curve. The graph includes chaotic like forms with delay.

Note that a lager limit circle is followed by a smaller one (see Fig. 3). A 28-days moving average form is selected. It looks like the main delays are coming from a one-month response of the system. This is the time period that should be taken under consideration when important actions are needed. No immediate response is possible. The reaction time of a large system as a country is critical.

From the graph 3 a center of the large cycles is located at 50 deaths per day whereas the center of aa smaller cycle is at 35 deaths per day. However, after 8th October 2021 the cycle is moving outside the small period expanded to a large cycle form with a center larger to 50 deaths per day.

Following the analysis above it is clear that the chaotic circles formation need much time to appear. It could that explained the very few papers appearing in the literature. A chaotic attractor is presented for the World covid-19 data without China in the paper by e Fernandes [1] while Debbouche et al. [5] study "Chaotic dynamics in a novel COVID-19 pandemic model described by commensurate and incommensurate fractional-order derivatives."

In the following the case of Greece is presented for total deaths/million population vs total cases (pop%) with comments (Fig. 4).[1]

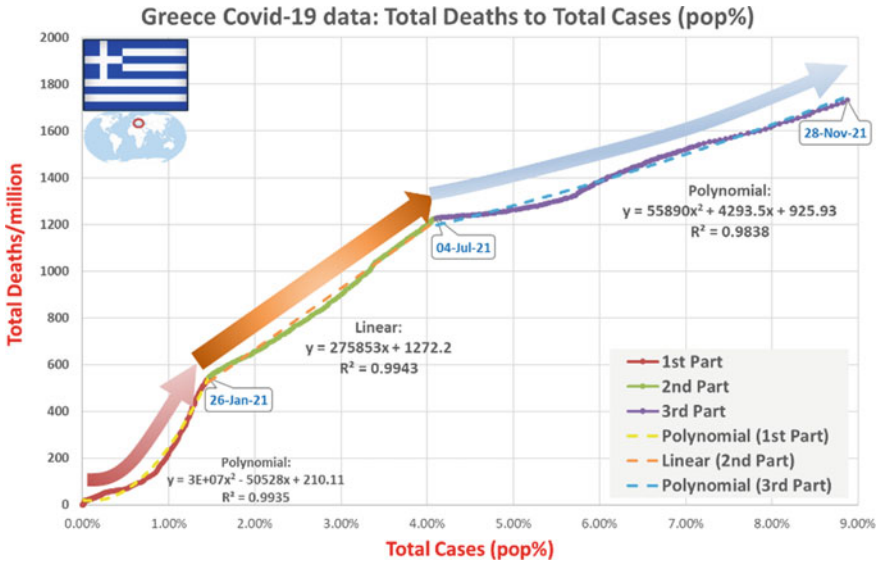

Fig. 4 Greece Covid19 data, total deaths to total cases

The slope of deaths vs cases curve declines rapidly in most countries due to: protection measures in vulnerable groups and improvement of medical treatment of cases (practically visible in the data curve of mortality from the disease).

3 Greece

The Part 4 completes the cycle on 10-Oct-21 and starts the Part 5 (5th cycle) which continues until the end of the available data (4 Nov-21) [because with Moving Average 28 days we have 4 nov + 28/2 days = 4 + 14 = 18 November. Each time we can form the circle 14 days before the end of the data].

For the initial wave propagation where part 1 at the beginning of the axes forms a small circle not clearly visible due to the graph analysis, we can see the following enlarged map forming the circle 14 days before the end of the data set (Fig. 5).

We observe that there is a cycle starting on March 4, 2020 (two weeks earlier due to MA = 28) culminating on 13 April (where the first differences = 0 ie the 1st derivative = 0 ≥ max). The cycle completes on July 8, 2020 where the first differences are zero again and part 2 begins.

[1] The authors invite readers feedback in YouTube® channel: *COVID-19 Data Analysis*: https://www.youtube.com/channel/UCa553hVoILqn4CJsIhiWW3w.

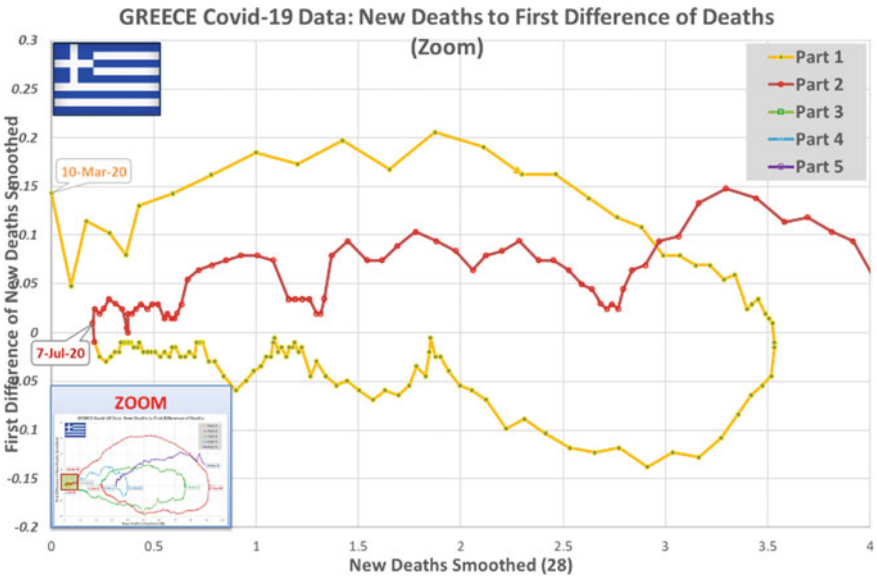

Fig. 5 Greece Covid19 data, new deaths to first difference of deaths (zoom)

We observe a small "transitional" period (from July 8, 2020 to October 21, 2020) when the cycle of part 2 (red) actually starts with the maximum reached on December 9, 2020. The cycle ends on February 11, 2021.

Then the Part 3 cycle (green) starts with a maximum on April 20, 2021 and completion on July 17, 2021. Immediately after, the part 4 cycle begins (blue) which reaches a maximum on September 12, 2021 and ends on October 10, 2021. This cycle must be due to the well-known Delta mutation that appeared in Greece in August 2021 and because it was more "contagious" it created a small cycle in the summer and with the vaccinated population of Greece over 50% (after July 2021).

The 5th cycle appear at October 10, 2021 and continues until today presenting a strong tendency to exceed the cycle of part 3 (Spring 2021).

A Greek characteristic is that the cycles move to the right in the X axis where more new deaths appear.

4 Brazil

Brazil is not known to have taken radical action against the pandemic. 28-day cycles have several periods of complex form. Furthermore, a central point of the epidemics cycles is far from the original point. Instead the point as at 1000 deaths per day (see Fig. 7). A further extended cycle has center at 1800 deaths per day (see Fig. 6). The enlargement of the graph for Brazil shows that the transition from the 2nd cycle to the

3rd cycle (at the end of Jan 21) took place immediately without a period of recession of the pandemic (semicircle in the negative region).

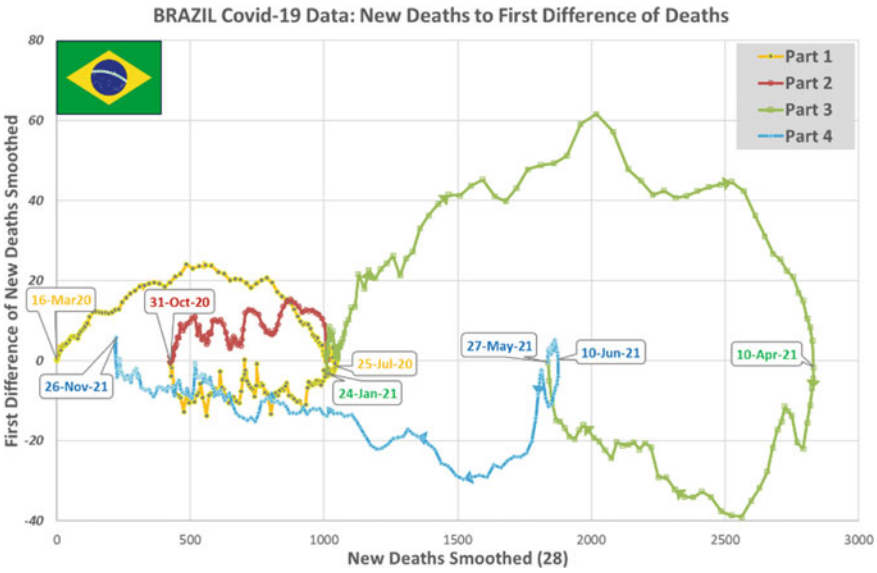

Fig. 6 Brazil Covid19 data, new deaths to first difference of deaths

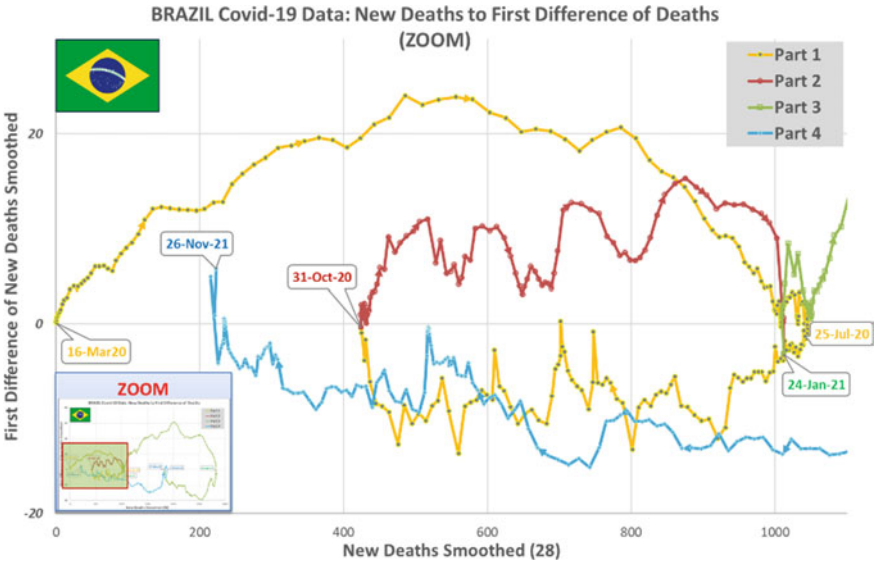

Fig. 7 Brazil Covid19 data, New Deaths to First Difference of Deaths (zoom)

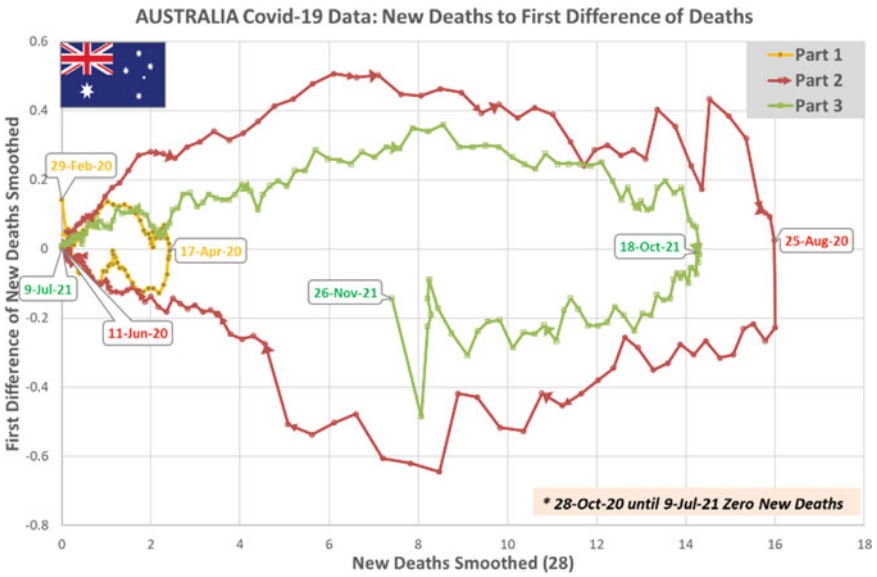

Fig. 8 Australia Covid19 data, new deaths to first difference of deaths

5 Australia

See Fig. 8.

For Australia only 3 circles are shown (the green is essentially "negligible" while the last one (blue) continuous.

Australia is the only country that managed for some time to eliminate deaths… (27-5 to 22-6/2020) and (28-10-20 to 9-7/2021). This is why we have only 3 visible circles in the graph.

6 Japan

See Fig. 9.

Japan is characterized by 5 limit cycles. The smaller 1st and 2nd (yellow and orange) appear in the first steps of the pandemic whereas the 3rd and 4th cycle periods are the larger. The 5th period shows a stabilization of cycle to a medium level with center at 30 deaths per day. Instead the 3rd and 4th cycle show a center at 60 deaths per day.

In Japan the 5 circles are visible and they are all complete. A characteristic is that the 1st and 2nd are extremely small!

The 1st, 2nd and 5th are completed with almost zero deaths in their completion.

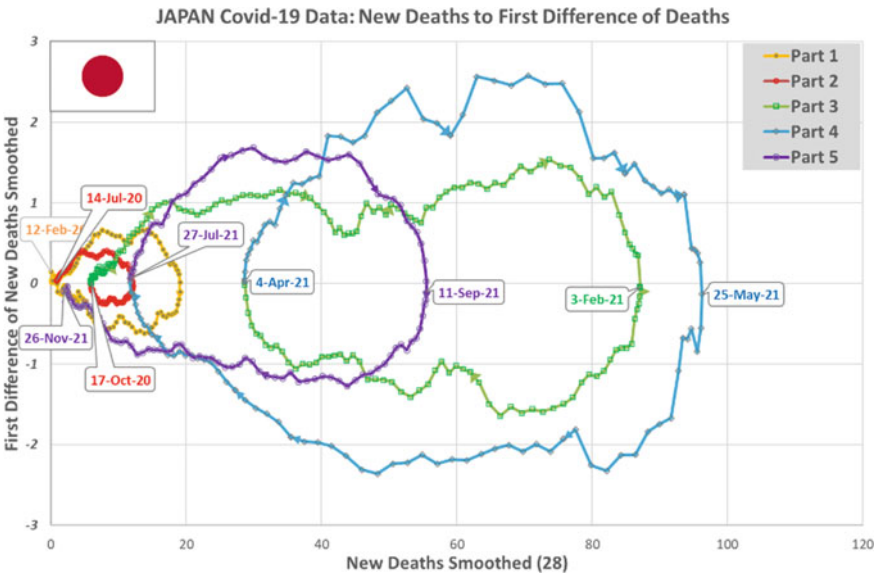

Fig. 9 Japan Covid19 data, new deaths to first difference of deaths

7 USA

See Fig. 10.

In USA the 1st, 2nd and 3rd cycles (yellow–red-green) start with a higher number of deaths than the next 4th cycle (part 4) (blue). However, the second cycle is smaller. The center for the first and second cycle are at 800 deaths per day that was expanded to 2000 deaths per day for the 3rd cycle and returned to 1000 deaths per day for the center of the 4th cycle.

8 UK

See Fig. 11.

UK is characterized by the simplicity of the cycles. The first two start and end at the origin whereas only the fourth starts after the origin and continuous as a small one until now. The center for the first cycle is at 400 death per day and at 600 deaths per day for the 2nd cycle.

The third cycle in the summer of 2021 is small and the 4th in the autumn of 2021 until today very small!

In the second cycle there is a “discontinuity” (13-Dec-20) that coincides with the period when the UK first adopted the vaccine and started mass vaccinations, while relaxing the measures.

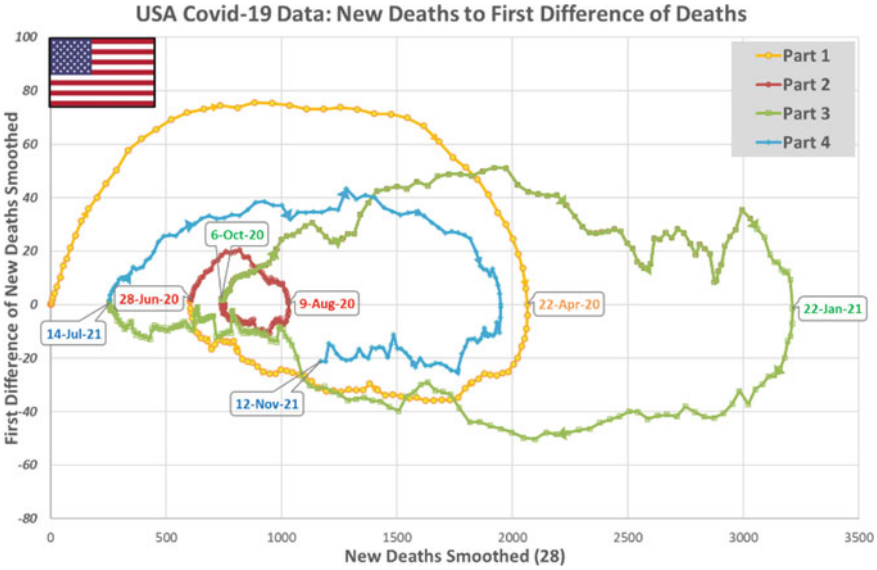

Fig. 10 USA Covid19 data, new deaths to first difference of deaths

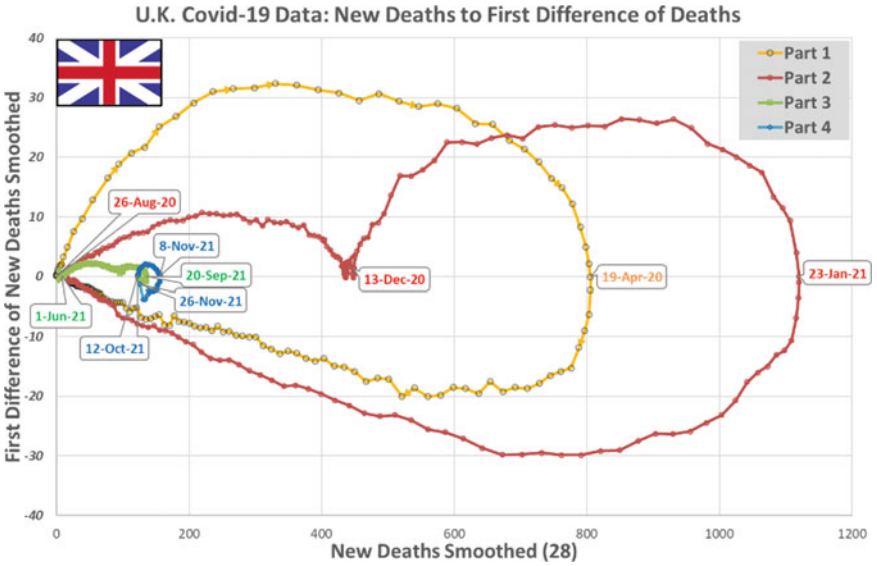

Fig. 11 UK Covid19 data, new deaths to first difference of deaths

9 Conclusions

The proposed methodology succeeds to simplify a relative complicated chaotic-like form of the Covid-19 death data set for various countries studied. Limit cycles result after a 28-day central moving average applied. The ±14-day two sided moving average methodology accepted, compatible with usual preferred quarantine period, seems to exclude small cycles and recycles that the applied state interventions produce.

Referring to the strategies adopted from the various countries studied as can be observed by the limit cycles formed, UK provides a simple and clear strategy leading to a low number of deaths per day after the first periods with a high number of deaths per day.

Greece follows a rather complicated covid-19 spread keeping the center of the cycles relatively far from the origin. The ongoing 5th cycle covers a region with high number of deaths per day as it was for the 2nd period of the pandemic. For this and for other countries is not clear what the best strategy is. Vaccine and keeping appropriate measures are proposed while the health system waits for new medicines.

Australia and Japan cope with small numbers of deaths per day. However, they provide limit cycles indicating a systematic state intervention keeping the spread under control.

USA cycle centers are relatively far from the origin whereas these centers are very far from the origin for Brazil.

References

1. T.D.S. e Fernandes, Chaotic model for COVID-19 growth factor. Res. Biomed. Eng. (2020). https://doi.org/10.1007/s42600-020-00077-5
2. C.H. Skiadas, C. Skiadas, *Chaotic Modeling and Simulation: Analysis of Chaotic Models Attractors and Forms* (Taylor & Francis/CRC Press, London, 2009)
3. C.H. Skiadas, Chaotic Modelling. In *International Encyclopedia of Statistical Science*, ed M. Lovric (Springer, Berlin, Heidelberg, 2011) https://doi.org/10.1007/978-3-642-04898-2_166
4. R.J. Hyndman, Moving Averages. in *International Encyclopedia of Statistical Science*, ed by M. Lovric (Springer, Berlin, Heidelberg, 2011). https://doi.org/10.1007/978-3-642-04898-2_380
5. N. Debbouche, A. Ouannas, I.M. Batiha et al., Chaotic dynamics in a novel COVID-19 pandemic model described by commensurate and incommensurate fractional-order derivatives. Nonlinear Dyn. (2021). https://doi.org/10.1007/s11071-021-06867-5
6. Data Retrieved from: https://ourworldindata.org/coronavirus [Online Resource] data accessed: 23 Nov 2021