
Efficiency of Covid-19 Containment by Measuring Time Dependent Doubling Time

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Abstract

While different containment measures of the Covid-19 epidemic have been applied recently a quantitative measure of their efficiency is not available. We show here that the time evolution of the pandemic doubling time $T_d(t)$ is a reliable measure of the efficiency of the Lockdown, Case Finding, Mobile Tracing (LFT) policy using modern technologies versus the traditional Lockdown Stop and Go policy. We have been able to verify theoretical predictions of the time evolution of the doubling time $T_d(t)$ and the particular features of each policy. The most successful containment policy reaches the lowest s factor, the characteristic time of the exponential growing doubling time in the arrested regime. South Korea, China, Italy and USA have reached $s = 5, 6, 10, 18$ respectively. The results clearly show that LFT containment policy has been able to reduce both the intensity and time width of the Covid-19 pandemic dome achieving both a low number of deaths and low economic losses.

The diffusion of Covid-19 is a transnational phenomenon that involves all continents reaching a million of positive cases and thousands of deaths at early April, 2020. Following the threshold of the very fast Covid-19 epidemic in January 2020 in Wuhan [1-2] it was found that a very small characteristic time (about 2 days) of the exponential growth and the characteristic number R_0 of infected humans by one infected case was about $R_0=2.3$, well larger than the critical value 1, pointing to an explosion of the pandemic with possible millions of infected humans in few weeks [3].

In the absence of a Covid-19 vaccine, scientists informed the policy makers for the urgent need of actions for controlling the pandemic [4] to reduce the expected number of hundreds of thousands of deaths in the short time of pandemic peak. The textbook epidemic control measures are addressed to reduce the number of daily new cases $N(t)$ to avoid an unacceptable load to the health care systems. The traditional method to reduce the number of deaths was the lockdown. It expands the time lapse of the virus diffusion by stretching the exponent of its exponential growth. Therefore while the number of cases will decrease at the top, the time extent of the epidemic will become longer with an increased negative impact to economy.

China first focused on an unconventional Covid-19 policy to reduce both the number of deaths and the time extent of the epidemic [1]. This unconventional policy called

"Lockdown, Case Finding, Mobile Tracing" (LFT) was based on the combination of measures. This policy looked to reduce both the number of new daily cases at epidemic peak and to reduce the time width of the pandemic peak. Achieving the reduction of both maximum and width of the diffusion peak this policy give the drastic reduction of the total number of deaths. Today after about 80 days from the epidemic threshold, on April 7th 2020 the long-term lockdown was "stopped" in China with less the 3400 fatality. It has been an "experiment" to test the efficiency of a new policy in the history of the epidemiology, which takes advantage of both mass search of positive cases and the tracing of infected cases by a mobile phone application. A similar approach has been considered by other countries, all taking advantage of advanced methods of new mobile phone technologies and the treatments of Big Data developed in the last years. The success of this approach for Covid-19 control was tested by Israel, South Korea, Singapore and Taiwan. [5]

An alternative policy has been considered by other countries such as USA and UK and was called "Lockdown stop and go" (LSC), a type of "herd immunity", after making criticisms to the contact tracing approach chosen by the P.R. of China [6]. The LCS approach is made of combination of advices for the population to keep "physical distancing" to protect others, to stay at home only for positive cases, household quarantine of their family members and to reduce traveling. Intermittent physical distancing measures are planned to be temporarily relaxed in short time windows, and reintroduced when case numbers rebound. [7] The media informed the population about the actual numbers of epidemic cases and the advices were diffused only weeks after the Covid-19 pandemic onset.

Other countries, e.g., France and Spain, have followed in March 2020 the Italian approach of "Mandatory Full Lockdown" (MFL) of the country with few days delay. This traditional epidemiologic confinement approach was strongly enforced and we call it here "Mandatory Full Lockdown" (MFL) policy. These unprecedented measures of imposition by law all over the country consist of physical distancing, ordering enforced closure of schools, universities, all national manufactures, ban of mass gatherings and public events, and confinement at home of the entire population.

This approach had the key target of reducing the number of infected cases day per day paying attention not to overcome the maximum number of person requiring critical care (invasive mechanical ventilation or ECMO) that can be hospitalized in any region/country. In fact, the MLF policy gives priority to the health care system respect to the economic demands.

Academic epidemiology analysis is usually made at the conclusion of the epidemic event. On the contrary, in the case of the Covid-19 epidemic some countries immediately shared verified data and made them available in public repositories. This opportunity gives scientists and expert in big data the possibility to apply new fast data analysis methods trying to shed light on the physics of this unique case of epidemic. The early results have shown that also Covid-19 follows the fundamental laws of epidemic spreading. However, in spite of the relevance of the question, none is able to measure in a quantitative way the success of the different containment measures based on verified Covid-19 data released by official institutions and health agencies.

Since in two previous papers [8,9] careful theoretical predictions of the modification of the epidemic growth curves due to containment measures for the Lockdown policies were

reported, it is now possible to check the theory with experimental results of epidemic spreading all over the world.

In previous papers [10,11] written on March 15, only two weeks after the start of the MFL policy, it was pointed out that the slowing down of the pandemic diffusion was much less effective for the MLF than for the LFT approach. The data analysis approach was focusing on the quantitative determination of the doubling time (T_d) of the Covid-19 pandemic spread calculated averaging *day by day* data over a 5 days interval [10,11]. Moreover it was possible to identify in the LFT controlled Covid-19 epidemic growth monitored in China and South Korea two well separated regimes: the first described by a stretching exponential with a slowly increasing stretched characteristic time followed by a second phase, the arrested or frustrated growth process following the Ostwald growth over the course of time, where one phase transforms into another metastable phase, but with a similar free energy [12-14]. This mechanism has been observed in the diffusion of oxygen interstitials diffusion in quantum complex matter [14-16] and in the crystallization of complex molecules [17] and proteins [18].

The different efficacy of the containment policies can be recognized in Figure 1a where the cumulative number of cases in different countries is plotted in the time scale with the zero sets at the first day of the exponential growth. As it can be seen in the panel (a) of Figure 1 the diffusion rate for the different policies in different countries is similar in the near threshold regime. Indeed, the reported curves of the cumulative number of cases $N_c(T)$ overlap in the near threshold regime while they strongly diverge in the arrested regime. The prediction of the variation of the doubling time for different control policies was made by Fergusson [8] and Goldenfeld [9] groups.

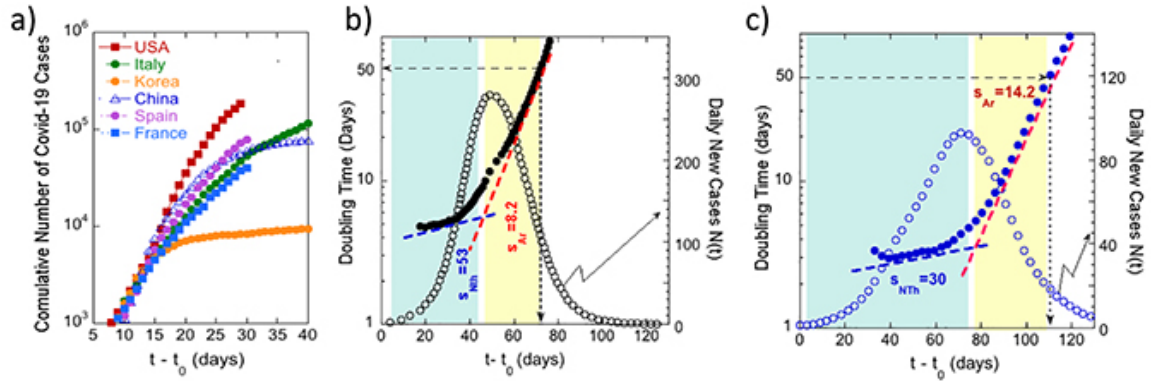


Figure 1. Panel a. Cumulative number of positive cases $N_c(t)$ vs. time in South Korea (orange), France (blue), China (light blue), Italy (green), Spain (magenta) and USA (red). The time scale for each curve of each country starts on the threshold day t_0 . The curves overlap in the near threshold regime while later separate. The curves of the cumulative number of cases of China and South Korea become flat after about 30 days, when the pandemic is arrested. **Panel (b,c)** the theoretical predictions for the curves $N(t)$ of the Daily New Cases (open symbols) from reference 8 for an uncontrolled diffusion (b) and for severe containment measures (c). The solid dots show the time dependent theoretical doubling time we obtained following calculations in ref. 8 for the two extreme cases (black and blue curves).

The panel (b) and (c) in Figure 1 show the pandemic dome in the curves of the numbers of daily new cases $N(t)$ calculated by Fergusson [8] for a wild uncontrolled diffusion (black open circles) and for a severe population lockdown (blue open circles). The predicted time

width of the dome increases by the control methods of the old epidemiology textbooks becoming 1.5 times wider as shown in panel (c) corresponding to a strong lockdown policy. In this work in order to measure the time evolution of the epidemic growth. we propose the use as the key physical term, the time dependent doubling time $T_d(t)$

$$T_d(t) = \frac{\ln(2)}{\frac{d[\ln(N_c(t))]}{dt}} \quad (1)$$

where $N_c(T)$ is the cumulative number of cases and the derivative at each time t is obtained by fitting the $N_c(T)$ curve over a period of five days.

The efficacy of the containment policies is probed by the curve of $T_d(t)$ increasing from its minimum value $T_{d0}=2$ days, at the threshold time t_0 to the value of $T_d=50$ days, which is the average time of the lifetime of the infected case, i.e., when the epidemic spread is expected to stop.

The theoretical curves $T_d(t)$ in panels (b) and (c) of Figure 1 show clearly a kink separating two different exponential increasing regimes: a the first near threshold regime (shaded blue region) and in the arrested regime (shaded yellow region) separated by the transition regime around the peak of the pandemic curve $N(t)$ of the number of new daily cases.

The predicted theoretical curves of $T_d(t)$ for the wild (black filled dots in panel b) and for the strong lockdown policy described in ref. 8 (blue filled dots) show relevant changes on the time evolution changes dependent on the policy.

The doubling time in the near threshold regime follows a first exponential growth (red line in the semi-log scale) with the characteristic time s_1 (or s_{Nth})

$$T_{d1}(t) = A e^{t/s_1} \quad (2)$$

and in the arrested regime follows a second exponential growth (blue line in the semi-log scale) with the characteristic time s_2 (or s_{Ar})

$$T_{d2}(t) = B e^{t/s_2} \quad (3)$$

where the theory predicts that s_2 (or s_{Ar}) is much smaller than the characteristic time s_1 (or s_{Nth}). Moreover it is possible to measure the average $\langle s \rangle$ factor by fitting the full $T_d(t)$ curve in the range $2 < T_d < 50$ introduced in ref. [10,11] to provides the quantitative measure of the efficiency and the effectiveness in term of time of the containment policy. The extraction of the $\langle s \rangle$, s_1 , and s_2 factors provides a direct quantitative evaluation and comparison of different containment policies adopted to control the epidemic.

We show using the predictions of the calculations in the near threshold regime that the factor s_1 decreases from the wild regime value $s_1=53$ days in panel (b) to the lockdown regime $s_1=30$ days in panel (c) and in the arrested regime the factor s_2 increases from the wild regime value $s_2=8.2$ days in panel (b) to the lockdown regime $s_2=14.2$ days in panel (c). The stop of the wild pandemic (defined as the value of time t where the doubling time T_d becomes 50) is predicted after 70 days while the stop in the most severe lockdown

policy is predicted after 110 days, i.e., the pandemic is predicted to be about 1.6 times longer in the lockdown regime in agreement with the ratio of the half width values at half maximum (HWHM). A theory needs to be verified or falsified according with the scientific experimental method [21].

The recent fast explosion of the Covid-19 pandemic has required a fast response of the scientific community to compare predictions with the data analysis of the Covid-19 data [22,23] to test immunization policies [24–26] and multiple containment measures [27–30]. Here in Figure 2 we report in the three panels the experimental doubling time $T_d(t)$ as a function of time, extracted by experimental verified data vs. time with the zero sets at the threshold time t_0 in several countries following different Covid-19 epidemic policy.

The time evolution of the experimental doubling time $T_d(t)$ for China and South Korea where the "Lockdown, Case Finding, Mobile Tracing" LFT policy was applied is plotted in Panel (a). The zero of the time scale is fixed at the time t_0 for the threshold of the exponential growth. The epidemic dome in both countries is shown by the curve of verified data of the counts of the number $N(t)$ of Daily New Cases.

The experimental doubling time is calculated using equation (1), and it does not need any normalization since $T_d(t)$ is given in units of days. The full lifetime A of the experimental epidemic dome is directly measured by the day where T_d assumes the value of 50 days, the lifetime of infected cases spreading the virus. We have found $A=27$ days for China and $A=24$ days for South Korea. After the time in the x axis has been divided by A , to get a normalized time scale, both the normalized domes of $N(t)$ and the experimental $T_d(t)$ curves for China and South Korea fully overlap providing evidence for a characteristic behavior associated with this policy.

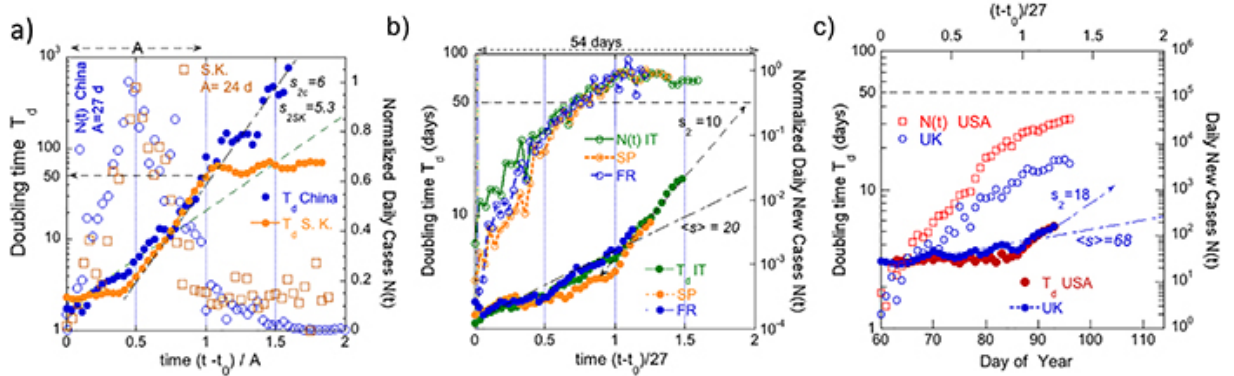


Figure 2. **Panel a)** Evolution of the experimental doubling time $T_d(t)$ in the countries where the LFT policy was applied: South Korea (filled orange dots) and China (filled blue dots). The open circles are the well known curves of the number of daily new cases $N(t)$ which are used here to track the time evolution pandemic domes. **Panel b)** the experimental time dependent doubling time $T_d(t)$ in the countries Spain (filled orange dots) and France (filled blue dots) and Italy, (filled blue dots) where the "Mandatory Full Lockdown" MFL policy was applied. **Panel c)** the evolution of the doubling time in countries USA (filled red dots) and UK (filled blue dots) applying the policy called "Lockdown stop and go" (LSC). The $N(t)$ curves are plotted in semi-log scale in panel b and c. In panel (a) and (b) the numbers in the $N(t)$ curves are normalized to overlap all curves in the near threshold region. In panel (c) the $N(t)$ curves are not normalized. The near threshold time regime in panel (b) and panel (c) identified at the time range between the threshold and the kink in the $T_d(t)$ is clearly 27 days in panel (b) and it seems to be similar in panel (c).

A key result of the data analysis is that the kink in the $T_d(t)$ curves, which separates the near threshold regime from the arrested regime, occurs at $t/A=0.5$, i.e., in the range of 13-14 days. The quite different values of the s_1 factor in the near threshold regime is due to the faster activation of the LSF policy in South Korea respect to China. In the arrested regime the s_2 factor for China is $s_{2c}=6$ and for South Korea is $s_{2SK}=5.3$ days, showing the most efficient control policy. The overlapping epidemic dome in both countries shows clearly that both the epidemic peak and its time lapse have been both strongly reduced. The average s factor for the two countries is around $s=7$.

The time dependent doubling time $T_d(t)$ in the countries (Italy, Spain, France) (filled blue dots) where “Mandatory Full Lockdown” MFL policy was applied fully overlap after normalization only of the time scale where the explosion time threshold has been used as the zero of the time scale. In the near-threshold regime the values of the doubling time are very similar and the three curves show the kink probing the transition from the near-threshold to the arrested regime at the same time i.e., 27 days, which has been used to normalize the time scale. In the arrested regime which has started only recently in the three countries the s factor is the same for the three countries, $s_2=10$. The average s factor for the two countries is around $\langle s \rangle=20$. From the fact that the exponential curve of $T_d(t)$ in the arrested regime is the line shown in panel 2, it is possible to predict the time needed to the stop of the main pandemic peak which is predicted to occur at 54 days from the explosion day t_0 in the three countries. While we can predict the exponential increase of the doubling time and when it will be $T_d=50$ days we cannot predict if at this time the number of daily new cases at saturation, as it occurred in South Korea.

The time dependent doubling time is plotted in panel (c) of Fig.1 for two countries USA and UK following the “Lockdown stop and go” LSG policy. In these countries while scientists requested their governments to activate as soon as possible containment measures the government was very slow.

In the near-threshold regime the doubling time in both country is very flat keeping a nearly constant doubling time 3.5 days indicating clearly that the government did not followed the scientific alarm and did not activated the containment measures. Moreover the explosion of the number of positive cases is in qualitative agreement with predictions for the wild pandemic spreading as predicted in Fig.1b. It is interesting to remark that recently the doubling time line for USA has shown a kink at 27 days from the explosion time at t_0 . The fact that the near threshold is the same as in panel (b) indicates that this is characteristic of the wild growth curve which was not stretched by the severe lockdown measures applied by the countries in panel (b). The huge effect on the number of positive cases and the number of deaths over the full epidemic dome in USA due the missing containment measures during the short critical time near threshold is indicated by the high value of $s_2=18$ for USA and the very high average $\langle s \rangle=28$ factor.

In conclusion we have tested the theoretical predictions of the time evolution of the doubling time $T_d(t)$ extracted from public data banks. The data clearly show that countries using modern technologies i.e., the containment policy "Lockdown, Case Finding, Mobile Tracing" (LFT) have been able to reduce both the intensity of peak in the curve of the daily new cases of the Covid-19 pandemic dome and its time duration compressing the dome only to a short time lapse of 27 days. Therefore they have achieved both a huge reduction of the number of deaths in their populations as well as the reduction of economic losses keeping manufacture lockdown as short as possible

Author Contributions: The authors contributed equally to the conceptualization, methodology, and investigation while preparing the article.

Funding: This research was funded by Superstripes-onlus.

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

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