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The ongoing COVID-19 epidemic curves indicate initial point spread in China with log-normal distribution of new cases per day with a predictable last date of the outbreak version 4: Predictions for selected European countries, USA and the World as a whole and try to predict the end of the outbreak including a discussion of a possible "new normal"

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Abstract

During an epidemic outbreak it is useful for planners and responsible authorities to be able to plan ahead to estimate when an outbreak of an epidemic is likely to ease and when the last case can be predicted in their area of responsibility. Theoretically this could be done for a point source epidemic using epidemic curve forecasting. The extensive data now coming out of China makes it possible to test if this can be done using MS Excel a standard spreadsheet program available to most offices. The available data is divided up for whole China and the different provinces. This and the high number of cases makes the analysis possible. Data for new confirmed infections for Hubei, Hubei outside Wuhan, China excluding Hubei as well as Zhejiang and Fujian provinces all follow a log-normal distribution that can be used to make a rough estimate for the date of the last new confirmed cases in respective areas. In the version 2 continuation work, 9 additional days were added for the Chinese data to evaluate the previous predictions. The extra data then available from China follows the previous predicted trend supporting the usefulness of this simple technique. In the version 2 we also tested the feasibility for a non-specialist to make similar predictions using additional data from S Korea now available. In this third continuation the predictions for Version 2 are evaluated for S Korea and fits well the beginning of the decline but it seems to be difficult to bring down numbers of cases per day under about 100 new cases per day, potential reasons for this is discussed. To further evaluate when in a prediction becomes reliable the Chinese data was used to evaluate to make predictions for each day around the peak in number of cases and after2-3 consecutive days of decreasing new cases per day the prediction becomes reliable. In version 3 data for Italy just reaching this point was used to make further predictions for that country. A second new analysis was also added to use the fitted equation to detect when the acceleration of new cases per day stopped increasing exponentially. In the Chinese case this measured point coincides with the date of the complete Hubei lockdown and in the new Italian analysis it coincides with the mandatory Italian lockdown. Predicted dates for the end of the Italian outbreak is also added. In version 4 we expand the analysis to selected European countries, USA and the World as a whole and try to predict the end of the outbreak. We further discuss the apparent success of the used techniques that might work to introduce a "new normal" not very different to the previous to stop secondary outbreaks of COVID19 and future COVIDs that are sure to come.

Introduction

 doi:10.20944/preprints202003.0077.v4

In epidemics starting as a point source the number of new cases often follows a log-normal distribution or more precisely a Poisson-Gamma distribution. How this distribution will develop over time can theoretically be determined by fitting a log-normal distribution equation to the data for new cases per day are reported. The estimate will of cause be more accurate the further into the outbreak. A literally "breaking point" for the accuracy of the estimate for the end of the outbreak comes after the number of new cases per day have reached its peak. From there on the estimate should be better and better. Here a simple method that could be used without access to special resources for getting such estimates after the peak has been reached is presented using data from the ongoing COVID-19 epidemic in China.

Results and discussion

A log normal distribution can be relatively nicely fitted all data sets (Fig 1&2). When using a log scale for the Y-axis it is apparent there are deviations in the early dates especially for Hubei (Fig 1A). This could be caused by a lag in detection of new cases in the beginning of the outbreak. The deviations in the latest dates can have many different causes like changing criteria for new cases, or simply a backlog in cases confirmation due to highly stressed health care system in the worst hit city Wuhan. Both the data from Hubei outside Wuhan (Fig 1B) and China outside Hubei (Fig 1C) on the other hand closely follows a log normal distribution.

To see if the same relationships holds also outside Hubei, two provinces with quite different number of cases, Zhejiang with many cases and Fujian with few cases, was also tested (Fig 2).

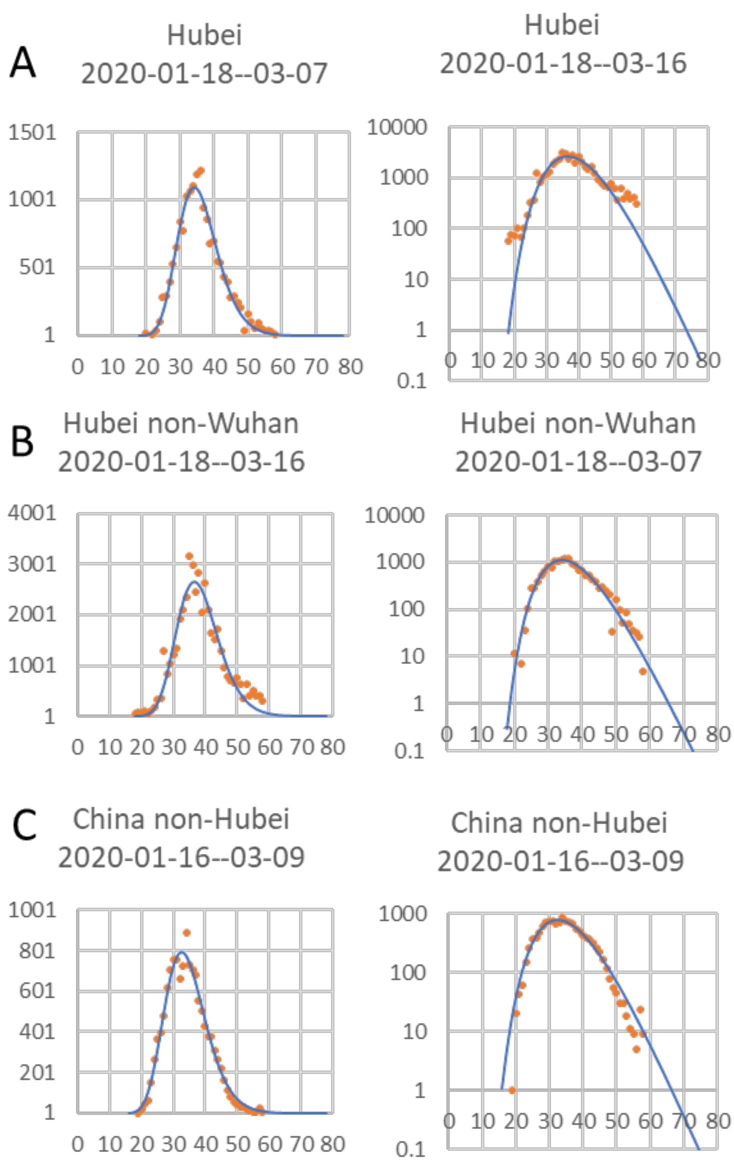

Figure 1. Log normal distribution of new confirmed cases for each day since 1 Jan 2020 Hubei, Hubei-nonWuhan and in reest of China. The Log of day values with start on the first day a case could have been confirmed was used curve fitting although here in the plot the actual number of days since 1st January was used as X-axis. Number of new confirmed cases per day and fitted curve (left) and Log number of new cases per day to show start and stop days (right). Headings shows estimated dates for 1st and last confirmed case. Y axes both to the left and right start at 1 to highlight the first and last case.

In Zheijiang the outbreak followed the general pattern very closely (Fig 2A) but for the much smaller outbreak in Fujian (Fig 2B) the number of cases per day dropped more than the model for the last days.This is caused by the approximation to log-normal distribution instead of a Poisson distribution that is more correct for data with few cases (Gonzales-Barron and Butler, 2011) but more difficult to handle using standard Excel curve fitting. This discrepancy mean that the last new infection date will be overestimated especially for limited outbreakes like the one in Fujian province. From planning point of view it should however be safer to oversestimate the length of the outbreak than underestimate it. A

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fairly good estimate of the last data could be done as soon as the number of new confirmed cases per day started to decrease.

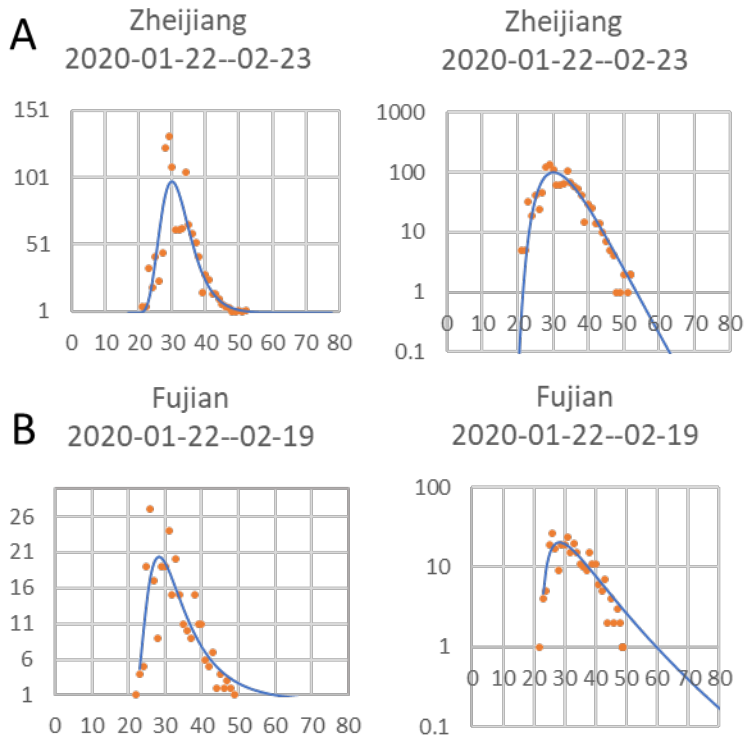

Figure 2. Log normal distribution of new confirmed cases for each day since 1 Jan 2020 in two provinces with relatively high numers of cases, Zeijiang with high numbers and Fujian with low numbers. The Log of day values with start on the first day a case could have been confirmed was used curve fitting although here in the plot the actual number of days since 1st January was used as X-axis. Number of new confirmed cases per day and fitted curve (left) and Log number of new cases per day to show start and stop days (right). Headings shows estimated dates for 1st and last confirmed case. Y-axes both to the left and right start at 1 to highlight the first and last case.

The estimated start date for when new cases could have been confirmed caused by community spread was for Hubei and Wuhan the 18th January while outside Hubei the data indicate a 2 day earlier start if the disease behaved similarly. This is a bit surprising but could indicate that the disease was brought to Wuhan city and Hubei province from a less populated area and found good conditions for spread in Wuhan. The estimated start dates for when new cases could be confirmed in the two provinces Zheijiang and Fujian were both the 22nd January a few days later than in the epicenter for the outbreak.

Test 9 days later if predictions were reasonable

In the follow up test of the original prediction the new data for the next 9 day follow the prediction (Fig. 1) surprisingly well (Fig. 1 continued). This applies for all three cases but especially good was the prediction for Hubei non-Wuhan (Fig. 1B continued). Interestingly, for China non-Hubei that previously seemed to predict a later end date than the data indicated (Fig. 1C), now with the new data it is apparent that this is not the case (Fig. 1C continued). Finally, for Hubei the decrease in new cases for the additional dates in principle follow the shape of the fitted curve but with a slight lag (Fig. 1A continued)

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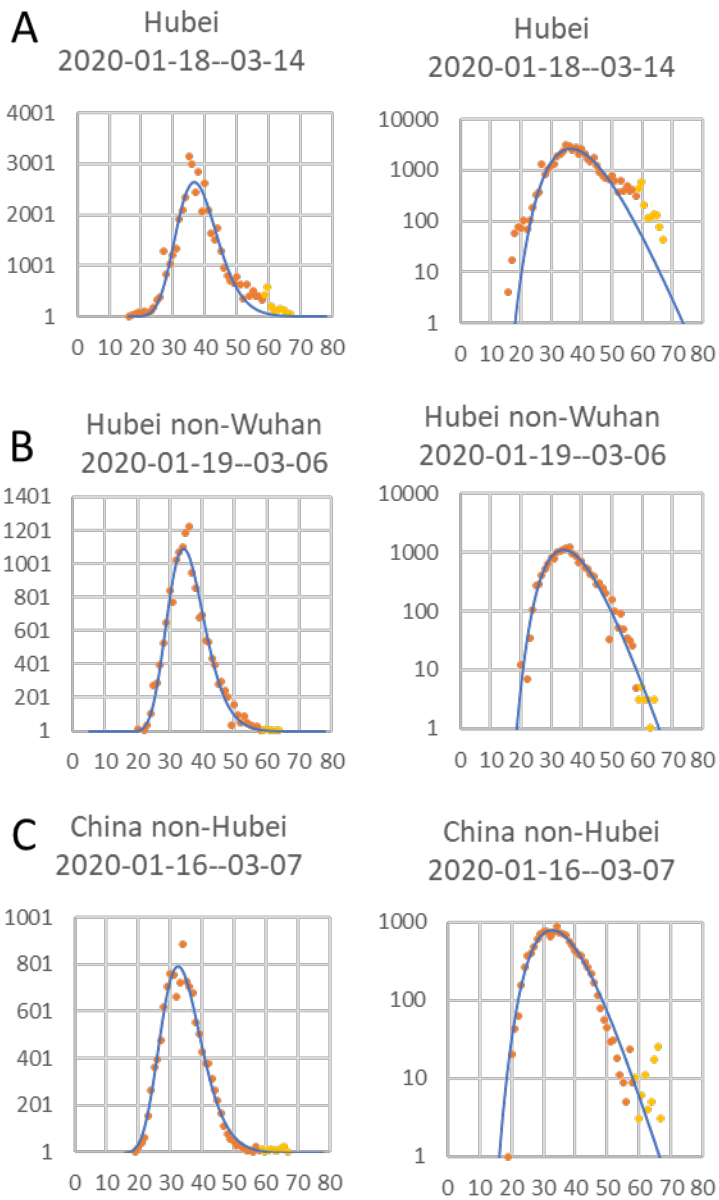

Figure 1 Continued. Follow up of the development seen in Figure to evaluate the predictions made previously. Same data and same data-fitting as in Figure 1 in manuscript V1 but with new data from February 27 to March 07 added (yellow dots). The Log of day values with start on the first day a case could have been confirmed was used curve fitting although here in the plot the actual number of days since 1st January was used as X-axis. Number of new confirmed cases per day and fitted curve (left) and Log number of new cases per day to show start and stop days (right). Headings shows estimated dates for 1st and last confirmed case. Y axes both to the left and right start at 1 to highlight the first and last predicted case.

Test if the MsExcel sheets with the instructions can be used by a non-bioinformatician

The Excel sheet was sent to a previous master student now living in another city (now also co-author) to test the feasability of using the sheets to do curve-fitting and predictions using the MsExcel file. After some initial problems finding out how to find the Solver Add-In for an iMac version of MsExcel things

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went smoothly. The problem was solved by the master student through an internet search for how to find and add the Solver Add-in to the iMac version. Also the S Korea data can be efficiently modelled using the same approach (Fig. 3).

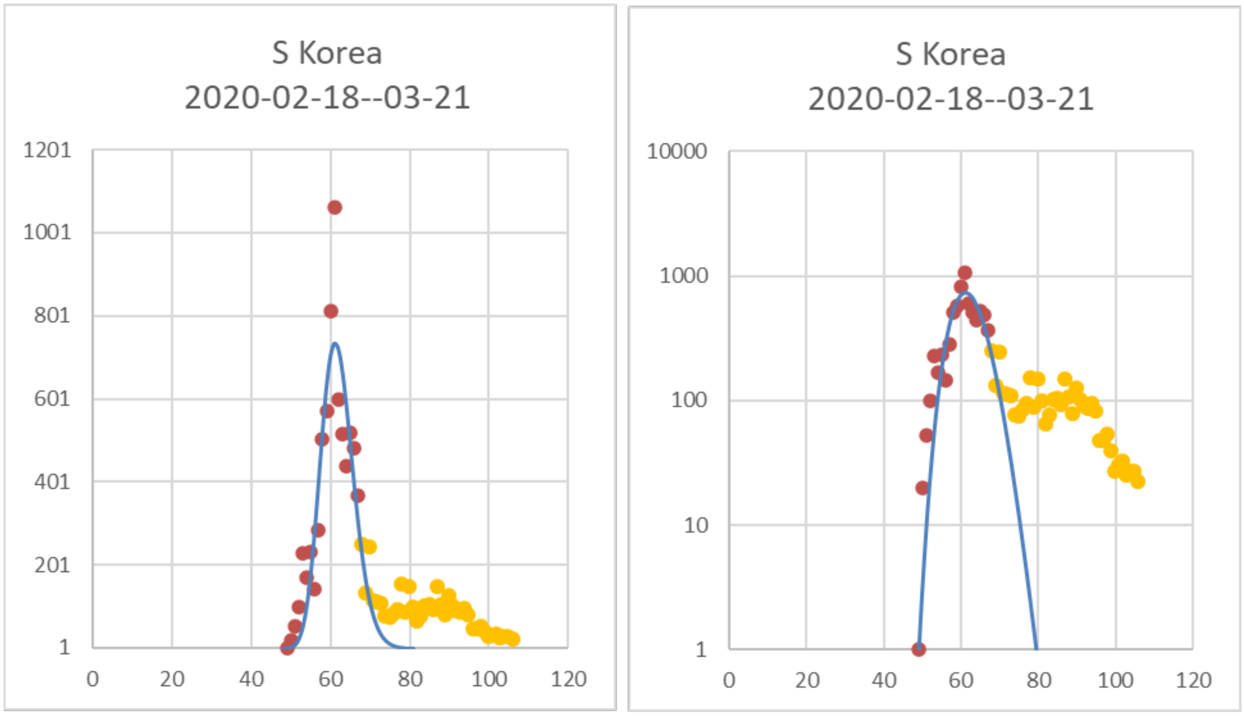

Figure 3 Continued2. Follow up of the development seen in Figure3 to evaluate the predictions made previously. The Log of day values with start on the first day a case could have been confirmed was used for curve fitting although here in the plot the actual number of days since 1st January was used as X-axis. Same data and same data-fitting as in Figure 1 in manuscript V2 but with new data from March7 to April 15 added (yellow dots). Number of new confirmed cases per day and fitted curve (left) and Log number of new cases per day to show start and stop days (right). Headings shows estimated dates for 1st and last confirmed case. Y axes both to the left and right start at 1 to highlight the first and last predicted case.

Test 27 days later if predictions for S Korea were reasonable

The first 3-4 days follows the predicted curve very close but the latest points stop declining at the level of about 100 new cqases per day there can be many explanations for this. One could be that the restrictions in S Korea was not a complete lockdown as in China alowiinfg a low level spread that maintains the levels of new infection. It could also be that in these cases are new infected cases leaking in from abroad. S Korea is not in the same situation as China was with basically no cases outside China or of cause a combination of both. April 15 (Version 4 of the manuscript) it became obvious that the difficulties to decrease below 100 new cases per day most likely depended on the very cases entering S. Korea from the rest of world (excluding China) since there came a second small “hump” around end of March (Day 85-92) when the increase was as greatest in the rest of the world (Fig 7).

Test when in an outbreak the predictions becomes reliable

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We have stated in the previos versions of the manuscript that one need to wait until at or after the peak in numbers per day to for the predictions to be reliable. Now we use the data for whole China to test this notion. We thus made predictions for consecutive day just before and after the peak in numbers per day. Thus we can plot curves showing these predictions and compare with where in the curve the predictions where made (Fig. 4). It is apparent that for the China data 2-3 days of decrease in numbers was needed to be able to reliable predict the magnitude and end of the outbreak (Fig. 4).

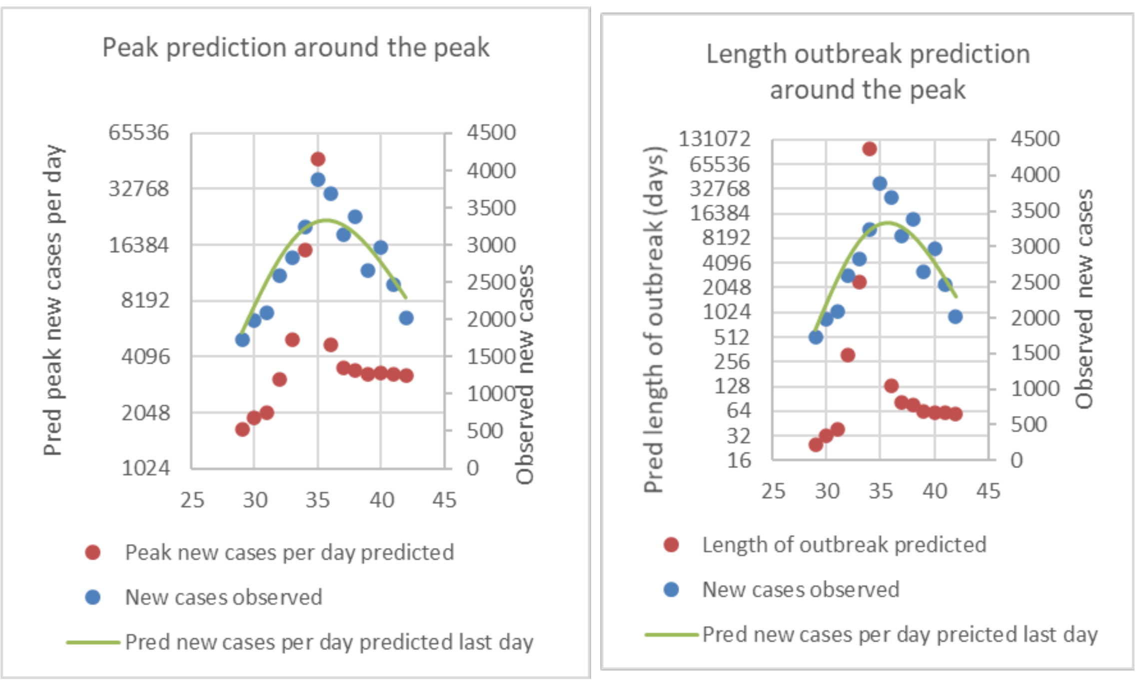

Figure 4. Analysis for when in an outbreak the analysis becomes reliable
Left: Prediction of peak hight using the data around the peak starting some days before the peak and finishing some days after the peak. Left Y axis shows a log scale for the predictions (red dots) and the right Y-axis show unlogged values for the observed values (blue dots) as well as the predicted fitted equation from the last day (day 42).
Right: Same as left figure but now with predicted length of the outbreak from predicted first to last case instead of peak height.

Use of the fitted equation to determine when the outbreak starts to slow down for then later to reach the peak new infections per day: Use on China data and on Italy data

An equation like the normal distribution has an acceleration phase, a slowdown of increase of acceleration then maximum acceleration before going into a deceleration towards the peak. Thus, the point where the acceleration of this acceleration starts to break is the point where something could have happened that determined the whole outbreak size and duration. To determine this the change in predicted new cases from one day to next (in principle the derivative of the equation) was plotted together with the predicted number of cases for the whole outbreak (Fig.5 Left). As can be seen in the figure the acceleration of the acceleration (the red curve) starts to slow down at day 28 (January 28) and the grid have been adjusted so that can be seen easier in the figure. A similar analysis was performed for the Italian data (Fig 5 right where it can be seen that the acceleration of the acceleration stops at day 70 (March 10). The Italian prediction data as of March 24 is also presented together with observed data (Fig 6).

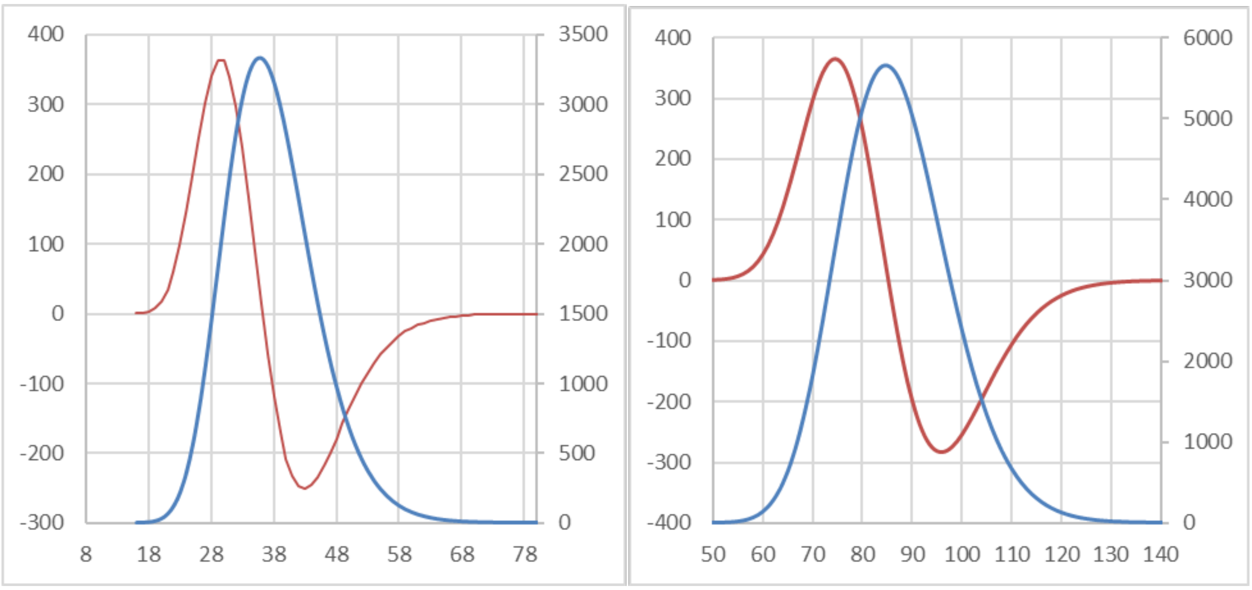

Figure 5 Plot of acceleration in new cases per day (red lines) together with cases per day predicted by the fitted equation (blue lines).
Values for whole China (left) shows that the Acceleration of the acceleration in new cases per day started to slow down on day 28 (January 28) (thus the unusual X axis to show that point with grid lines). Values predicted for Italy (right) shows a similar change on day 70 (March 10) Left Y axes are increase in numbers of new cases per day and right Y axes shows new cases per day. X-axes is days since start of year 2020.

As can be seen for Italy new cases are predicted to start falling at around March 24-25 and the outbreak is predicted to get its last case on May 23 if present measures by the Italian government is kept. With even stronger measures this could maybe be shortened and total cases lower. If measures are relaxed the whole outbreak becomes longer and total number of cases will increase.

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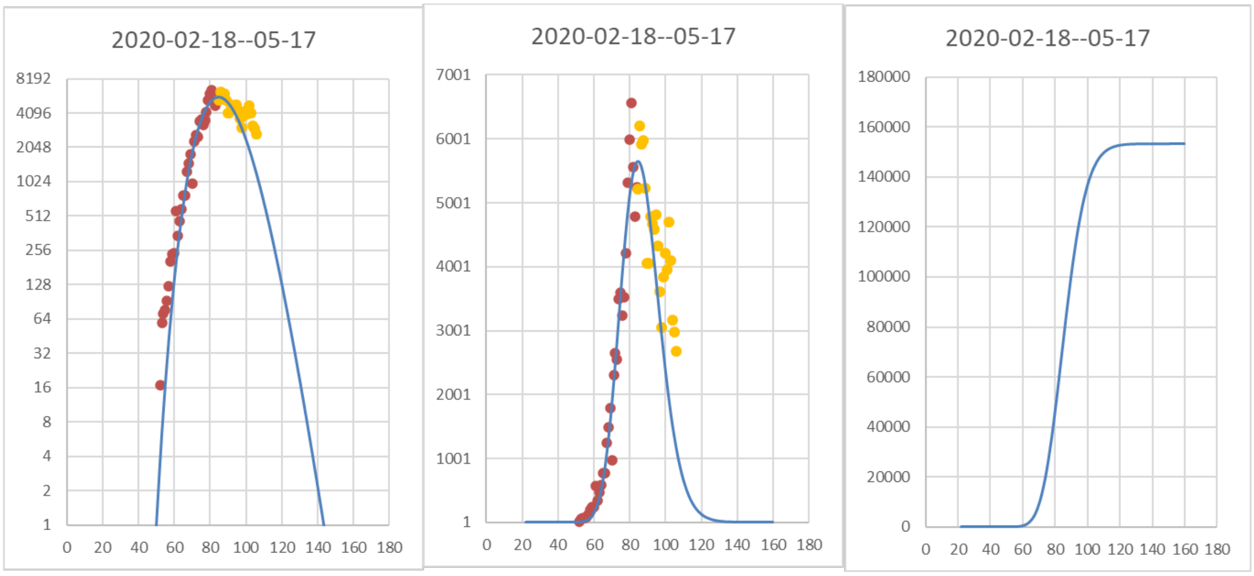


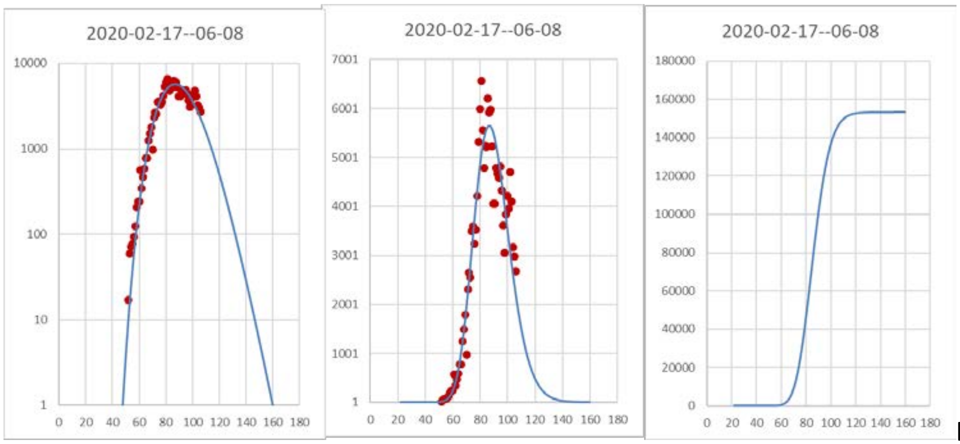
Figure 6. Continued. Predictions for Italy the 24th March 2020 with follow up 15th April
The Log of day values with start on the first day a case could have been confirmed was used for curve fitting although here in the plot the actual number of days since 1st January was used as X-axis. . Same data and same data-fitting as in Figure 1 in manuscript V3 but with new data from March 24 to April 15 added (yellow dots). Log number of new cases per day to show start and stop days (left), number of new confirmed cases per day and fitted curve (Middle) and cumulative predicted curve (right). Headings shows estimated dates for 1st and last confirmed case. Y axes both to the left and middle start at 1 to highlight the first and last predicted case.

Test 22 days later if predictions for Italy were reasonable

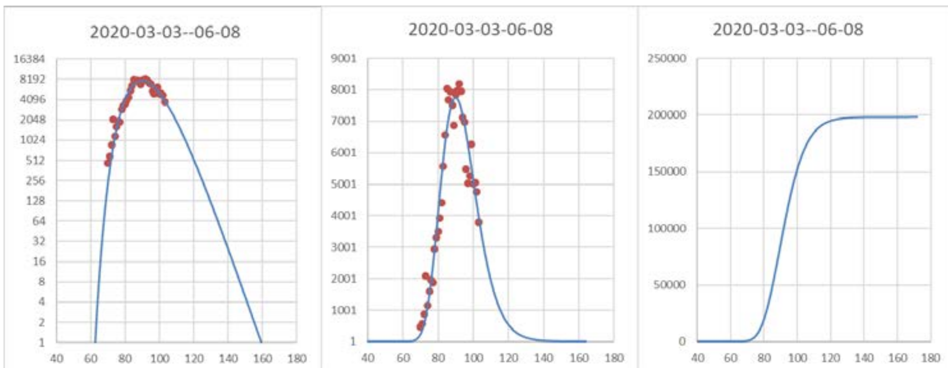
It was apparently a bit too early in the curve the 24th March to accurately predict the shape of the curve. The prediction underestimated the number of new cases after that date and thus also underestimates the likely length of the outbreak. The difference is not large but clearly visible (Figure 6 orange Dots). A new prediction that better reflects the datapoints was made (Fig 7) and now the predicted end of the outbrake is now June 8 instead of May 17. Thus the total lengt of the outbreak is predicted to be 113 days instead of 94 as previosly predicted.

Predicting the COVID19 outbreak in selected European countries, USA and the World.

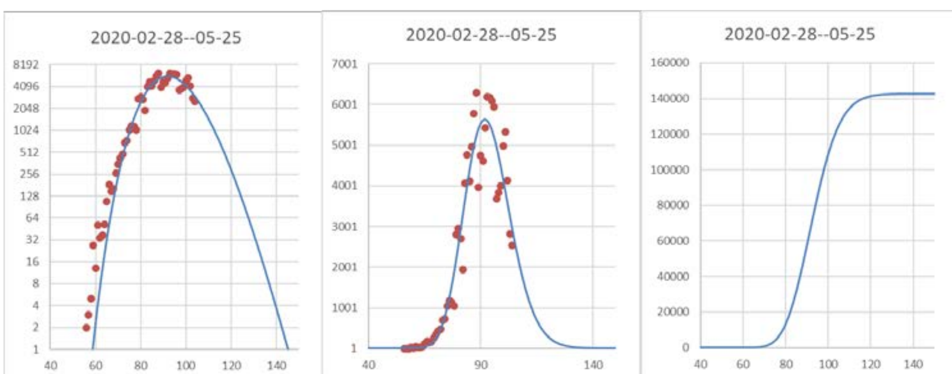
The pandemic has spread to almost all countries in the world. After some initial uncertenties and delays most countries have enforced lockdowns or encouraged social distancing and in effect tried to limit the spread of the COVID19. In most countries this is done using a combination of social distancing, testing and tracing contacts. From the data of the April 15 this actually seems to work (Fig 7).



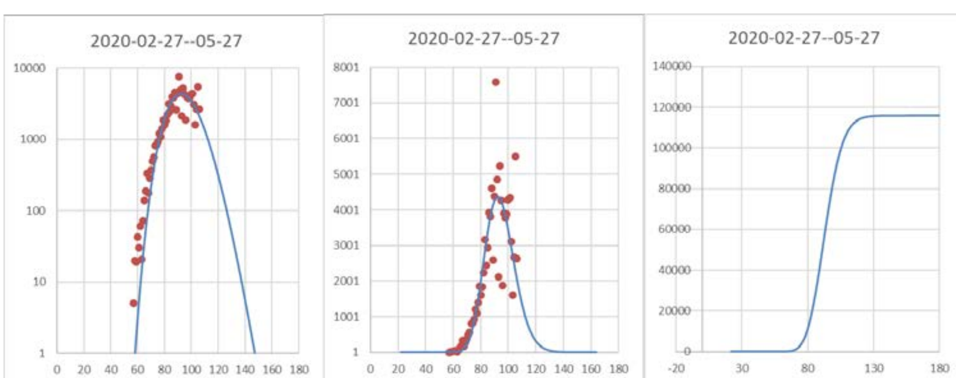
Italy 181,447



Spain 198,134

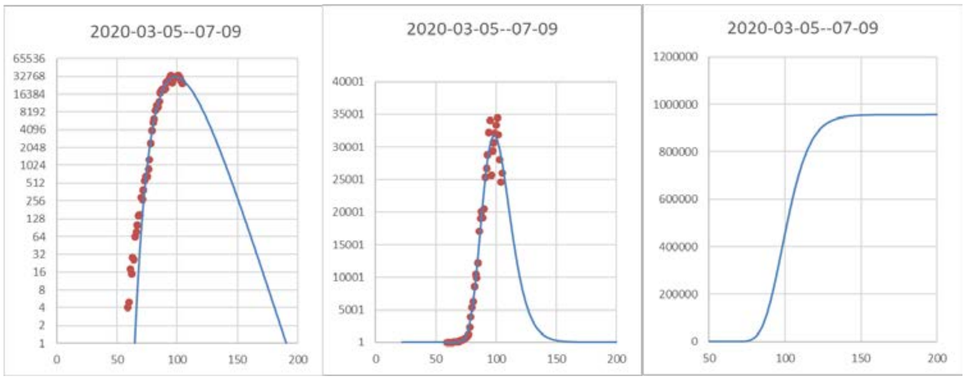


Germany 146,058

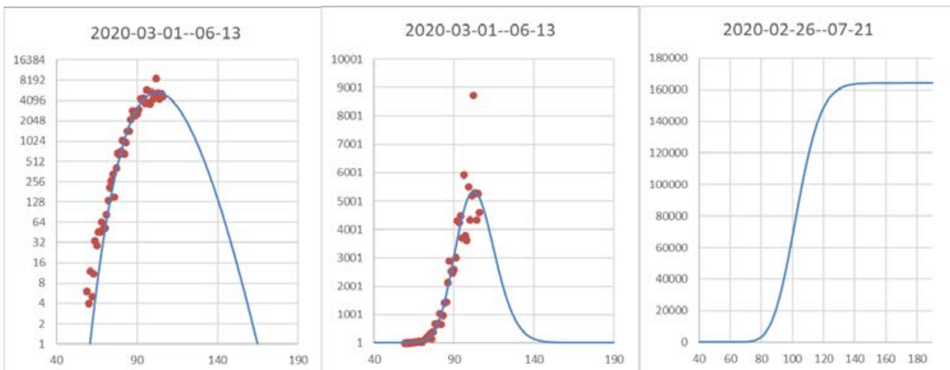


France 115,938

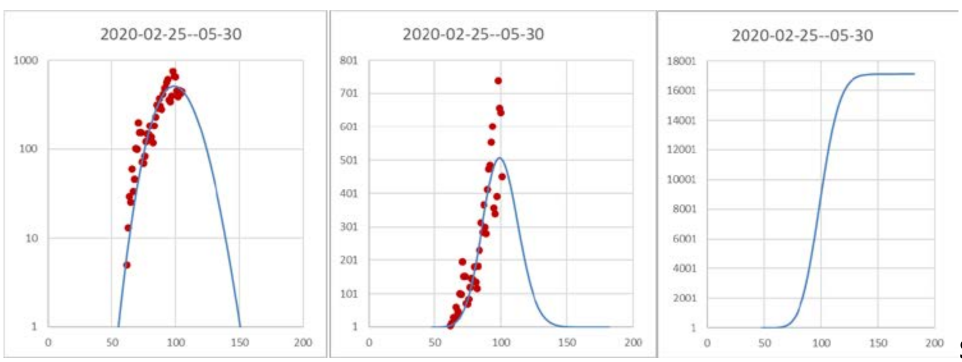
Figure 7. (Continues on next page)



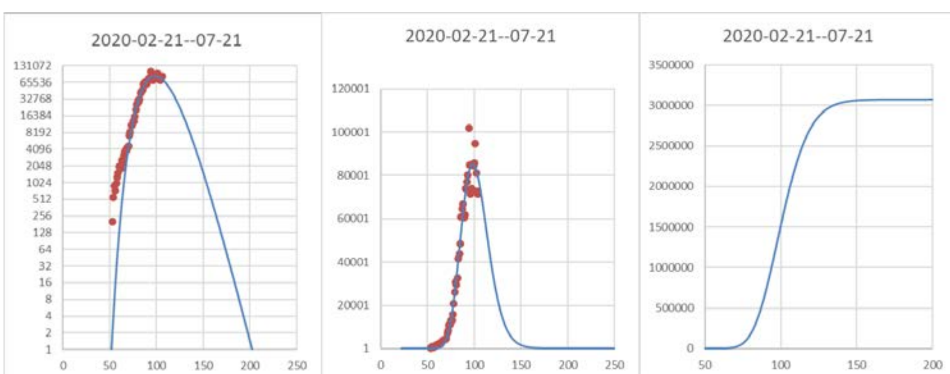
USA 1,028,334



UK 164,481



Sweden 17,116



World 2,802,340

Figure 7. Log normal distribution of new confirmed cases for each day since 1 Jan 2020 Some European countries, USA and the. The Log of day values with start on the first day a case could have been confirmed was used for curve fitting although here in the plot the actual number of days since 1st January was used as X-axis.

Number of new confirmed cases per day and fitted curve (left) and Log number of new cases per day to show start and stop days (right). Headings shows estimated dates for 1st and last confirmed case. Y-axes both to the left and right start at 1 to highlight the first and last case. To the right of each set of figures name of country or region and the predicted total number of confirmed countries in theat country or region. Plots for countries are ordered from top to bottom in order of security of prediction with the top countries more secure when it comes to outbreak lengt and total number of registered cases.

It is also obvious from Fig 7 that the outbreaks can be modelled using the same type of equation. From our predictions it looks like the COVID19 outbreak could be over in Europe and USA already in July-August 2020 and in the World maybe at roughly the same time if the relatively early measures most countries have introduced works.

The day the acceleration of cases stopped was the day lockdowns were enforced.

Since January 28 for China and March 10 for Italy marks the day when the outbreaks took a new direction according to our analysis and the acceleration of the acceleration of new cases started to slow down we decided to look up that day in the WiKi-pages (Anonymous, 2020a) that also records the decisions taken by officials to see if anything unusual happened those days. For China the mandatory lockdown of Hubei was announced the January 28 and the lockdown was in effect the 29th. For Italy the lockdown was similarly introduced on March 10. This may point to the importance of an early lockdown as in China since it took effect when there were around 1000-1500 new cases per day. In Italy the same did not happen until there were more than 2000 new cases per day only 2-3 days later in the outbreak. This difference seems to double the length of the outbreak and triple the total number of cases compared to China (Fig. 6).

Conclusion

Plotting new confirmed cases per day against time can be used during a large point source epidemic outbreak to relatively early after the peak in new cases determine a likely last date for new cases. Such information should be useful to people in charge for planning how to allocate resources. The information will also be available when resources are as most stretched with a large number of active cases just after the peak in number of new cases per day, In addition, if the data continue to fit the curve for a point source outbreak in one area there has most likely been no new introduction of cases or any change to the virus or the likelihood that a person becomes infected within that area. The latter seems to be the case for the COVID-19 outbreak in China 2019-2020 pointing to that the quarantining measures stopping further spread between provinces and cities after the first few days of person-to-person transfer have worked efficiently.

In this extended work (V2) we tested the predictions for the 9 following days in the previous preprint paper (or version) against the new data and we found that the technique managed to predict the new data very well. In addition, we have now also found that it is feasible to put the Excel file in the hands of a non-bioinformatician and get useful results as can be seen for the S Korea newly added figures (Fig. 3).

In this further extended work (V3), we evaluated the predictions previously made for S Korea and found that predictions were valid but inflow from other countries and some minor outbreaks and/or not

 doi:10.20944/preprints202003.0077.v4

strong enough measures might make it difficult get the outbreak to completely disappear. We have in V3 added an analysis for when the prediction using our method becomes reliable and that happens a few days after the peak where number of infections per day start a reliable decline. We also in this version added an analysis of when new infections pre day stopped accelerating with the same rate. We then found that it was rather early in the China case and only some days later for Italy. To our big surprise Both these dates coincide with the days mandatory lockdown took effect in both countries. The few days later in the outbreak lockdown in Italy is then also a probable cause of the higher peak and is predicted to result in 2 times longer outbreak with 3 times higher numbers of total cases than was the case for China. Thus a few days hesitation taking the lockdown decisions appears to have had huge effects.

In this further extended work (V4) we analyzed the outbreaks in selected European countries, USA and tried to predict the outcome for the world. To our great surprise different types of lockdowns and social distancing seems to work to end the outbreaks. The epidemic curves have roughly the same shapes and seem to become very predictable. As we pointed out in the V3 the timing of the lockdown or advice to socially distance appear to be crucial. It is also obvious that the social distancing measures can be very different in different countries and still work depending on density of people and culture. Prof Olsson originally from Sweden was critical to the very light measures taken in Sweden but thought it might actually work. Sweden have no dense population and compared to many other countries in Europe and especially in Asia social distancing is the normal anyway. On top of that most old people live at home in their own which is very good flats and houses until the last months of their lives. Thus, there are few old-people's homes today in Sweden. Socially maybe this is not so good but definitely an advantage with COVID19 in the society. The World predictions are a bit unsure since but measures to break the transmission of the virus has been taken already in all large countries in the world so the world predictions might not be so far off after all. If they come through that would be fantastic and encouraging. With the techniques available today, temperature checks where people gather and other places in society combined with compulsory testing if someone is detected with fever and tracing (that can be made anonymous and voluntary) with the help of mobile applications it should be possible to return to a "new normal" not very different from before also without a vaccine. These modern technologies, IR fever checks, mobile phone tracing, and PCR-testing might make it possible not just to keep COVID19 under control but also early detect and control next COVIDs without developing vaccines that takes time prove to be safe enough. Even then they are not always very efficient and can sometimes cause negative side effects in some people. Next COVID could potentially be much worse so it would be good to develop a "new normal" that does not necessarily involve social distancing unless there is an ongoing outbreak in a local area. This "new normal", should also be able to catch other contagious respiratory tract diseases and limit their spread including the seasonal influenza and colds and limit their negative effects on society.

Methods

Official referred to data for the COVID-19 outbreak is collected at a Wikipedia pages (Anonymous, 2020b, 2020a). Data for Sweden was not well updated at these pages so these were collected from the official Swedish Government page (Folkhälsomyndigheten, Sweden). World data was not available at the Wikipedia pages so they were obtained from Worldometer (Worldometer)

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Since the kind of analysis here presented is a relatively simple analysis it should be possible to do for anyone using a standard program Microsoft Excel with the standard available Solver plugin for data handling and curve fitting. The logarithm of number of days since the estimated start of the epidemic outbreak were used for fitting a normal distribution equation to the data but in the figures the data was plotted against the non-logged day number with day 1 on the 1st January to ease in determining the actual dates from readings on the X-axis and the values in the spreadsheet files.

The MS Excel file used for this analysis is available as Supplementary file and can easily be modified to be used with other data to relatively early after the peak in new confirmed cases be able to predict the end of an epidemic outbreak with a definite starting point having a "first case".

Acknowledgement

When back in my home country Sweden I had to decide when to return to China after the winter break for the Chinese New Year (Spring Festival), I decided to look at the epidemiology data since I have been working with biological control trying to cause epidemics in fungal pathogens attacking plants. I thought of looking for data about the COVID-19 outbreak to be able to determine a time and a route back that limit the chances for me to catch the infection and bring it to my workplace. I found the very good Wikipedia entry I refer to in the methods and would like to thank everyone that has contributed to edit that site. Finally, I want to acknowledge my employer Fujian Agriculture and Forestry University that makes it possible for me to do research in China.

Supplemental file

"Corona model final.V3.xlsx" is a supplemental file containing all pervious data for China with an added Sheet for Whole of China. This sheet contains prediction reliability data and the data for calculating and showing the acceleration of number of cases per day. In addition, the file also contains instructions for how to use it to fit new data to make predictions.

"Corona model only S-Korea and Italy.V4" is a supplemental file containing the previous data sheet from V3 with the previous prediction fit to new data. This file also contain data for Italy used for a fitting and prediction similar to what was done for Whole of China in the other Supplemental file "Corona model final.V3.xlsx".

"Corona model Europe US and World.V4" is a supplemental file containing predictions for the size and the end of the outbreaks for Italy, Spain, Germany, France, United Kingdom, Sweden, USA and the World.

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