Modeling region based regimes for COVID-19 mitigation: An inverse Gompertz approach to coronavirus infections in the USA, New York, and New Jersey

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Abstract
The world tried to control the spread of coronavirus disease 2019 (COVID-19) at national and regional levels through various mitigation strategies. In the first wave of infections, the most extreme strategies included large-scale national and regional lockdowns or stay-at-home orders. One major side effect of large-scale lockdowns was the shuttering of the economy, leading to massive layoffs, loss of income, and livelihood. Lockdowns were justified in part by scientific models (computer forecast and simulations) that assumed exponential growth in infections and predicted millions of fatalities without these ‘non-pharmaceutical interventions’ (NPI). Some scientists questioned these assumptions. Regions that followed other softer mitigation strategies such as work from home, crowd limits, use of masks, individual quarantining, basic social distancing, testing, and tracing – at least in the first wave of infections – saw similar health outcomes. Clear results were confusing, complicated, and difficult to assess. Ultimately, in the USA, what kind of mitigation strategy was enforced became a political decision only partly based on scientific models. We do not test for what levels of NPI are necessary for appropriate management of the first wave of the pandemic. Rather we use the ‘inverse-fitting Gompertz function’ methodology suggested by anti-lockdown advocate and...
Nobel Laureate Dr. Levitts to estimate the rate of growth/decline in COVID-19 infections as well to determine when disease peaking occurred. Our estimates may help predict levels of first-wave infections in the future and help a region to monitor new outbreaks prior to opening its economy. The inverse fitting function is applied to the first wave of infections in the USA and in the hard-hit New York and New Jersey regions for the time period March to June 2020. This is the earliest days of pandemic in the USA. The estimates for the rates of growth/decline are computed and used to predict underlying future infections, so that decision makers can monitor the disease threat as they open their economies. This preliminary and exploratory analysis and findings are discussed briefly and presented primarily in charts and tables, but the following waves of disease diffusion are not included and certainly were not anticipated.

**KEYWORDS**
COVID-19, economic impacts, exponential growth, Gompertz curve, lockdowns, mitigation, social distancing

1 | **INTRODUCTION**

When faced with a sudden emergence of a potentially deadly infectious disease that has no immediate cure; decision makers are likely to resort to wide-scale regional and national lockdowns. The lockdowns are part of a risk management regime that is deemed necessary to stop the disease from growing exponentially. The main goal is to ‘flatten the curve,’ so that existing healthcare resources can handle inevitable increases in hospitalizations and visits to emergency rooms and intensive care units.

That being said, lockdowns result in local, regional, and national consequences, leading to massive layoffs as well as loss of livelihood and incomes for millions of people, causing economic hardships in a population that is already under severe health-related stress. Further, for a country the size of the USA, these disease outbreaks occur asynchronously in different places over different periods of days, weeks, or months. Further, the interaction across the US physical space was unanticipated and not responded to at the national or even regional level. For example, outbreaks on the West Coast predated those on the East Coast by nearly a week, while the outbreaks in some of the southern and in Midwest states were a few days to a few weeks later than on the West Coast (Figure 1). Finally, the local state management (public health care) systems responsible for responding were not equipped to manage it locally, let alone across multistate and multiregional interactive settings.

Adding to the mass anxiety was not knowing how long the disease will run its course. Although Western states had outbreaks that started earlier and appeared to be under control, some of those areas had smaller outbreaks as late as the second week of May, even as they were part of the wider regional shutdowns that were in effect from the later half of March through the first three weeks of May. On the other hand, some of the southern states went...
on to open their economies quickly by cancelling NPI mitigation rules without immediately seeing substantial resurgence in disease intensity.

In open societies like much of the Western world where free flow of information – both good and bad – is a given, state and local policy makers are keenly aware that they are on borrowed time in assuming an implicit permission from citizens for the continuation of shutdown policies. It is assumed here that these policy decisions are carefully evaluated on the basis of a number of inputs that presumably include scientific analyses. In all countries, these decisions are political and much of the process behind these decisions remains opaque. As a result, countries developed a variety of mitigation strategies ranging from very strict, as in the case of China, to very loose and voluntary, as in the case of Sweden and in the beginning the UK and in-between. A mix of mitigation strategies developed, with some being quite successful, as in the case of Taiwan, South Korea, Iceland, and New Zealand, who relied heavily on testing, tracing, and individual quarantining rather than massive lockdowns.

The role of science is often difficult to appreciate and conflicting in interpretation. A case in point is the Scientific Advisory Group for Emergencies (SAGE) committee appointed by the UK government for the coronavirus pandemic. For much of February and through the first couple of weeks of March 2020, the UK government had decided to go with a loose set of guidelines that assumed voluntary participation from the public to control the spread of the coronavirus. However, all that changed almost overnight, when the SAGE committee learned about the alarming results of a computer simulation model from one of its members, Prof. Neil Ferguson (Imperial College London). The then unpublished report (Ferguson et al., 2020) claimed that its model predicted that, in absence of any non-pharmaceutical intervention (NPI), nearly 80% of the population will get infected and total mortality could be as high as 2.2 million in the USA and over 500,000 in the UK. The UK government announced a nation-wide lockdown.

**FIGURE 1** Log-linear plot of COVID-19 cumulative confirmed cases for select states from 22 January to 15 March 2020, where by 15 March 2020, every state had at least 25 cases
the very next day (20 March 2020). The USA, however, continued to use its decentralized federal system, with state health evaluation and response procedures determined at the local level with little national guidance or role modeling.

The shocking fatality counts from the Ferguson simulation based on a scenario of the pandemic with no mitigation intervention may have influenced actions of many governments across the globe in justifying stricter social-distancing regimes (Adam, 2020). It appears to have influenced even the Trump administration while it was trying to talk up, but not require, its recommendation for social distancing.2

Initially, the USA had declared a national emergency and recommended (13 March 2020) that states develop a 30-day stay-at-home and social-distancing advisory on 16 March 2020 (The White House, 2020a). It was extended on 29 March (The White House, 2020b) to last through the end of April 2020. At least five states did not follow these suggestions, and many made them optional.

It is important to note that in a constitutionally based federal system of government such as the USA, the national government may have little control over what happens in each state in areas of education and health. Each state’s governor has the authority to issue and implement that state’s set of rules/guidelines on what type of mitigation (social-distancing regime) is followed within its borders (Gershman, 2020). Further, the federal government was limited by poor or no planning, was undersupplied with needed support equipment, and had a nonexistent testing system with no plans for linking any testing to tracing procedures.

States with large susceptible population groups and/or what appeared to be out-of-control outbreaks issued stricter social-distancing measures including stay-at-home policies with near total shutdown of all commercial and noncommercial activities (including religious places). The only exceptions were essential services. At the other end of the social-distancing spectrum were the recommendations in some states, such as Nebraska, Arkansas, Iowa, and the Dakotas (North and South), that never issued stay-at-home orders and had a very loose set of guidelines on what was allowed and what was banned (for example, large gatherings). The messy decision-making process of lockdown/no-lockdown varied from state to state. In the end, it was a combination of policies related to ‘flattening-the-curve’, the threat of exponential spread of the contagion, the mixed messaging from the federal government, and the divided politics that contributed to the atmosphere of fear and doubt among the people. This led, in the private sector, to massive layoffs and brought the US economy to almost a complete halt.

2 | BACKGROUND

Overwhelmed by the rush of bad events, economic meltdown, and rising daily infection and casualty counts, it seemed that hardly anyone in the scientific community questioned whether COVID-19 was spreading exponentially and what was the necessity or usefulness of national or statewide shutdowns. There were a few exceptions with varying advice, including Prof. Sunetra Gupta, the well-known epidemiologist, Dr. Ben-Israel, Space Science Center leader in Israel, Dr. Karl Friston, Neuroscientist and Professor at City University of London, Dr. Johan Giesecke, Sr. Advisor to Swedish Government and the World Health Organization (WHO), and Dr. Michael Levitt, Nobel Laureate Professor at Stanford University.

Each of them subscribed to some form of social-distancing regime – especially targeted at lockdowns for vulnerable population groups and limiting large gatherings, but none of them supported the strict stay-at-home lockdowns for the entire population for one singularly important reason: it would send the economy into a precipitous fall (Master, 2020).

The other thought behind objecting to strict lockdowns is that the virus may be highly infectious, but the vast majority would likely not get the disease, and if they did, the high level of infections would confer ‘herd’ immunity that in turn would protect the rest of the population at least for a short time. Additionally, it would save the economy from the precipitous decline that was happening all over the world. Nearly all of the experts noted that the virus was already circulating through the population before the strict lockdowns went into effect; some of them thought that
the virus would follow its own life cycle (Dr. Ben-Israel and Dr. Friston) and decline accordingly, and at least some of them thought that exponential growth in the spread of the virus (Dr. Michael Levitt) would not happen. These experts, from a variety of experiences and disciplines, all agree that without a strict social-distancing regime, the virus will spread across the globe. However, they questioned whether the virus was likely to kill a significant level of the population. The main objection was about general acceptance that COVID-19 would grow exponentially without a widespread shutdown, and the other was whether one could ignore the enormous economic costs associated with such lockdown policies.

For example, Dr. Ben-Israel, Israeli Space Agency, came up with an easily computable statistic that showed when each country or region peaked and the degree of decline in the COVID-19 spread following the peak (Isaac Ben Israel, 2020). The statistic is computed as a simple ratio of daily new cases to cumulative cases of COVID-19. Further, he claimed that the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the causative agent behind the COVID-19 disease, would follow its own life cycle that spanned roughly 70 days. In other words, it would be self-limiting irrespective of what mitigation/social-distancing regime is implemented (Knapton & Gilbert, 2020). One problem with Ben-Israel’s statistic is that the ratio always starts with the peak and keeps declining afterwards since the daily new cases are always less than cumulative cases. Despite this, it does provide an easily computable statistic that can be compared across space and time. At the very least, it may provide a way to measure effectiveness of different disease management regimes followed in different regions.

Prof. Sunetra Gupta, from Oxford University who studies evolutionary biology of infectious diseases, thought that SARS-CoV-2 was already circulating among the population and that the strict shutdown policy was too late to stop the spread, and that now Britain was faced with a worsening economic disaster (Vardarajan, 2020). She blamed the lack of early response on long-term neglect and underfunding of the UK national health service. She thought that targeted quarantines would be better able to control future outbreaks while the rest of the economy continued to work for the people. She had similar opinions when it came to India’s response of total shutdowns to fight coronavirus. She thought that India, with its relatively young population (majority under 60 years), could have managed to keep its economy working instead of doing a nation-wide lockdown (Thapar, 2020). She suggested that large-scale serological testing would help identify areas with higher numbers of infection and that these could be targeted for social-distancing measures while the rest of the country could go back to work (Lourenco et al., 2020). In many ways, this follows the typical strategies used in containing earlier bacterial and virus outbreaks (polio, smallpox, Ebola, etc.).

Dr. Friston, a neurobiologist from City University of London, who is part of an independent group of scientists – referred to as ‘shadow’ SAGE in the media, noted at the time, that there were too many unknown variables that affect COVID-19 and its causative agent SARS-CoV-2 and that a typical epidemiological susceptible–infected–recovered (SIR) model (Kermack & McKendrick, 1927) may not be sufficient to capture the dynamics of these unknown variables. Instead, he proposed a ‘Dynamic Causal Model’ to study SARS-CoV-2. This model, according to Dr. Friston, predicts that nearly 80% of the UK population was immune to SARS-CoV-2 and that COVID-19 had already peaked when the UK instituted its strict mitigation regime (stay-at-home/lockdown) or even its looser mitigations (Daunizeau et al., 2020; Moran et al., 2020). Of course, this meant that a “not-as-stringent” mitigation/social-distancing strategy would save the UK economy from collapse.

Dr. Michael Levitt, Nobel Laureate from Stanford University, was visiting China in January (2020) when the coronavirus outbreak began. He analyzed China’s coronavirus data when he was back in the USA (Levitt & Sandford, 2020) and noted that there never was any danger of the coronavirus growing exponentially (Sayers, 2020). As mentioned above, disease transmission and spread models are based on the classical SIR model (Kermack & McKendrick, 1927) that uses sigmoid functions. Others (Ord & Getis, 2018) have successfully used SIR models with sigmoid and Gompertz functions (Mitcehn, 2020). Dr. Levitt believed that the Gompertz function was a better fit for the cumulative infection data than a logistic function. As per his analyses, no matter what type of soft mitigation/social-distancing regime is followed by any country, the growth function in each of the country level analyses has a negative exponent, indicative of a decay function (Levitt & Stanford, 2020) that will eventually slow the virus.
3 | METHODOLOGY

In these first days of the pandemic, we decided to use the ‘inverse function fitting’ methodology suggested by Dr. Michael Levitt to analyze the coronavirus infection data for the USA at the country, state, and county level. Such analyses, we thought, could help with the following goals of our study:

A. To assess whether the infection data at the country, state, or county level showed exponential growth any time during the study period.
B. To identify when the infections peaked and estimate the time of peaking.
C. To determine the rate of decay as the infections start decreasing.

Goal A was to help identify whether there ever was an exponential growth danger to potentially impact the healthcare system (already under severe stress) that could lead to its breakdown. Were there areas where hospitals would be unable to provide care for the increasing caseloads? Lack of hospital care would significantly increase mortality in a region. Goals B and C would help to monitor the date of peaking and estimate the time in days when local healthcare systems and hospitals in any jurisdiction would be under pressure to meet the needs of existing and new infections.

Towards these goals, we used raw cumulative data from the Johns Hopkins University (JHU) COVID-19 data source (JHU COVID-19 Dashboard, 2020) to extract data for the COVID-19 confirmed cases from 22 January to 15 June 2020.

We expected the cumulative confirmed cases by county to be monotonically nondecreasing over the study time period. However, there are many counties (small jurisdictions) where cumulative cases on successive days show a decrease (Equation 1 below) rather than a constant number – when there are no new cases – or increasing cumulative cases when new cases are reported.

\[ c(t) < c(t-1) \]  

where \( c(t) \) = cumulative cases on day \( t \) and \( c(t-1) \) = cumulative cases on day \( t-1 \).

The downloaded data were checked, and they were adjusted to make the time series monotonically nondecreasing such that

\[ c(t) \geq c(t-1). \]  

(2)

Next, we computed daily new cases \( d \) on day \( t \):

\[ d(t) = c(t) - c(t-1), \]  

(3)

As mentioned in the three goals above, we wanted to determine whether any of the US jurisdictions had exponential growth during the current study time duration; if and when the peaking occurred; and, for past peaking, what the nature of decreases in infections was, that is, either a steady or a bumpy decline.

We decided to use the Gompertz curve following Ord & Getis (2018) as the inverse fitting function to the monotonically nondecreasing cumulative infection data. The Gompertz function shown in the equation below (The White House, 2020b) is a special case of the sigmoid function and is suitable to describe a phenomenon that seems to unexpectedly emerge and grow over short time periods and then appears to asymptotically reach a plateau.

\[ G = Ke^{-be^{-at}}, \]  

(White House, 2020b)

where \( K \) is the asymptotic value at time \( T \) (the duration of study period), \( a \) is the rate of growth, and \( b \) is the horizontal drift.
The nature of the difference curve described by Equation 3 also contributed to the choice of Gompertz instead of a typical sigmoid curve. Cumulative data based on the sigmoid curve show a symmetric bell-shaped difference curve where the number of cases before and after the peak are equal; such a distribution of data is highly unlikely in the case of an ongoing pandemic. On the other hand, a difference curve computed from a Gompertz function shows a distribution with a ‘fat tail’ in its decline after a peak is reached. In fact, the difference curve data covering our first-wave analysis does indeed show an asymmetric distribution around the peak where the post-peak decline is described by a bumpy or ‘fat tail’. In other words, a Gompertz function can describe this asymmetric bell curve with a fat tail decline that takes a longer time to decay than the rapid rise to the peak. We decided to analyze the national pattern and then to disaggregate the data into active regional patterns that, at that time, dominated in terms of what was happening in the states and cities of New York and New Jersey.

These regions had the highest cumulative counts of infections. In this first wave, it appears that from 29 February to 15 June 2020, many of these regions had multiple outbreaks – indicated by total number of infections staying constant for few days and then suddenly increasing to higher levels of infections4

Here the coronavirus cases from 29 February to 15 June 2020 for the USA and select states are for different jurisdictions and peak at different times. For example, New York peaked around 15 April, while New Jersey and the USA peaked 24 April and 25 April, respectively.

These are log difference curves. In other words, these are the slopes of the cumulative count curves.

Figure 5 is essentially an integration of Figures 2, 3, and 4. It shows for the USA and a limited set of states comparative log-linear plots of cumulative confirmed cases along with respective rates of growth computed as log
**FIGURE 3** Daily counts of COVID-19 confirmed

**FIGURE 4** Log-linear plots of COVID-19 cumulative confirmed coronavirus counts for the USA and select states (29 February to 15 June 2020)
difference between consecutive cumulative confirmed cases. It also shows linear plots (secondary Y axis) of respective daily counts of the confirmed cases. The rate of growth for each state is plotted as a log values of change in cumulative values for successive days. Nearly all the states show a declining trend from a high value on the left toward low values to the right.

5 | RESULTS USING INVERSE CURVE FITTING

Our first-wave analysis covers the cumulative infections data by state for a total of $T = 102$ days from 6 March to 15 June 2020. The choice for the time duration was partly decided because of the multiple short duration outbreaks exhibited by many states between 22 January and 5 March 2020. Each such short outbreak would need to be handled as a separate curve fitting problem that is not only complex, but parameters of such curves are likely to be riddled with the underlying noise of the data collection process. It helps to have data that instead have one single outbreak. Note that even this so-called single outbreak time duration has a few minor glitches, but they are far and few and therefore do not affect the overview analysis.

The output is shown for the USA and the states of New York and New Jersey in Figures 6, 7, and 8, respectively.

Table 1 shows the parameters associated with fitted Gompertz curves for the USA, New York, and New Jersey.
**FIGURE 6** The US COVID-19 cumulative confirmed cases, slope and linear plot of daily confirmed (second Y-axis on the right) case counts, and fitted Gompertz G function, G function slope, and G function daily cases for the USA

**FIGURE 7** New York COVID-19 cumulative confirmed cases, slope and linear plot of daily confirmed cases (second Y-axis on the right), and fitted Gompertz G function, G curve function, and G function daily cases for New York
**Figure 8** New Jersey COVID-19 cumulative confirmed cases, slope and linear plot of daily confirmed case counts (second Y-axis on the right), and fitted Gompertz G function, G function slope, and G function daily cases for New Jersey

| TABLE 1 | Parameters derived for fitted Gompertz curves for the USA, New York, and New Jersey |
|---------|----------------------------------------------------------------------------------------------------------------------------------|
| Gompertz function $G = K \times \exp(-b \times \exp(-at))$ | Asymptote $K$ | Rate of growth $a$ | Horizontal drift $b$ | $R^2$ |
| USA | 2,107,800 | $-0.054$ | $-5.026$ | 0.99847 |
| New York | 383,950 | $-0.065$ | $-7.561$ | 0.99924 |
| New Jersey | 167,100 | $-0.062$ | $-9.303$ | 0.99939 |

| TABLE 2 | Estimate of number of days and date when expected number of new infections drops by $(1/e)$ |
|---------|-----------------------------------------------------------------------------------------------|
| New infections on 15 June 2020 | Number of days $d$ when cases drop to $(1/e)$ level of 15 June 2020 | Expected number of new infections at the end of $d$ days | Date at the end of $d$ days | Expected number of new infections at the end of $(2 \times d)$ days | Date at the end of $(2 \times d)$ days |
| USA | 19,887 | $\sim19$ days | 7,338 | 7/4 | 2,708 | 7/23 |
| New York | 620 | $\sim16$ days | 229 | 7/1 | 84 | 7/17 |
| New Jersey | 222 | $\sim17$ days | 82 | 7/2 | 30 | 7/18 |
Table 2 shows the estimates of the number of days computed from the fitted Gompertz curves for the USA, New York, and New Jersey when the COVID-19 new confirmed cases drop by a level of \((1/e)\) or below levels on 15 June 2020.

6  |  CONCLUSIONS

There was a time delay of nearly 2 weeks before the first infections of COVID-19 spread to all 50 states.

The US and the state of New Jersey’s first wave, both peaked around 25 April 2020, while the New York peak occurred around 15 April 2020.

Based on the Gompertz curve fitting, there never was any indication of the growth occurring at an exponential rate; in fact, the rate of growth has been declining at a rate of almost 5.4\% for the USA, while the decline is about 6.5\% for New York and 6.2\% for New Jersey, during this first wave. Based on these declining growth rates, it would take almost 19 days for the US infections to reduce to \((1/e)\) levels of 15 June 2020. For New York, the equivalent number of days is 16 and nearly 17 days for New Jersey.

Of course, this never happened. These are estimates based on the COVID-19 infections as of 15 June 2020. These estimates are unlikely to change for New York and New Jersey. However, since US estimates are based on aggregate data for the 50 states, the statistics are sensitive to large-scale changes in any of the 50 states (except New York and New Jersey). The case in point is that abandoning a social-distancing regime altogether such as what appears to have happened in many southern and western states during the Memorial Day weekend would negatively affect these results, and it did!

7  |  FUTURE DIRECTIONS

We understand that this approach broke down in the second and third waves that followed and, therefore, nationally. However, we would like to confirm the application methodology of reverse curve fitting of the Gompertz curve to sub-regional data (groups of states/Census regions and at the county level) and for metropolitan regions. In the first COVID-19 wave, it assumes isolated populations and not the overall state and regional interactions that followed in secondary and tertiary waves. Further, we note that the diffusion of the disease is not adequately captured in this simplistic approach, but it does provide a building block for alterations and changes. Also, we plan to compare the COVID-19 infections and mortality data for other states and counties that followed minimal mitigation/social-distancing regimes with those following a stay-at-home or lockdown approach for limiting infection expansion.

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ENDNOTES

1 Confirmed cumulative coronavirus cases > 25 in a county
2 ‘I think you know from that large blue mountain that you can see behind me – and I just want to thank the five or six international and domestic modelers from Harvard, from Columbia, from Northeastern, from Imperial who helped us
tremendously. It was their models that created the ability to see what these mitigations could do, how steeply they could depress the curve from that giant blue mountain down to that more stippled area. In their estimates, they had between 1.5 million and 2.2 million people in the United States succumbing to this virus without mitigation. Yet, through their detailed studies and showing us what social distancing would do, what people – what would happen if people stayed home, what would happen if people were careful every day to wash their hands and worry about touching their faces, that what an extraordinary thing this could be if every American followed these. And it takes us to that stippled mountain that is much lower – a hill, actually – down to 100,000 to 200,000 deaths, which is still way too much.’

https://www.whitehouse.gov/briefings-statements/remarks-president-trump-vice-president-pence-members-coronavirus-task-force-press-briefing-15/

3 https://www.gov.uk/government/publications/scientific-advisory-group-for-emergencies-sage-coronavirus-covid-19-response-membership/list-of-participants-of-sage-and-related-sub-groups

4 The sudden jump in numbers may also be partly due to uneven collection and reporting of confirmed cases, which in turn is likely due to variation in the times needed by a variety of testing procedures to confirm COVID-19 infections.

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