Visualizing Covid-19 Data

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TLDR

- Covid-19 has been spreading globally with over 2,000,000 people infected. Over 700,000 people are infected by Covid-19 in the US. Disease containment efforts are relatively more effective in some Asian countries and regions.
- In ths US, the growth in confirmed cases has become slower recently. However, there is also a signal of inadequate testing. The metric, positive rate of Covid-19 tests, can be used to measure the sufficiency of tests relative to the spread of the disease. It grows from 15% to 20% in the past month.
- Cross-state comparisons are possible despite the variation in testing policies. It can be done by jointly analyzing positive rate and number of tests per million population – For two states with similar numbers of tests per million population, positive rate is a proxy for the severity of the spread of Covid-19.
- The number of deaths is a more reliable metric than the number of positive cases. The situation in some states (such as NY) starts to stablize according to this metric. A projection of the trajectory of Covid-19 is done based on a simplified version of IHME's method. Similar results are reproduced.

Introduction

The goal of this report is to visualize the spread of Covid-19 and to understand the development of this public health crisis. We begin by a brief overview of the spread of Covid-19 across the globe and in the US. We then move onto the closer analysis of the US data at state-level. In particular we visualize the trajectory of the spread across time for individual states as well as compare the states and making projections.

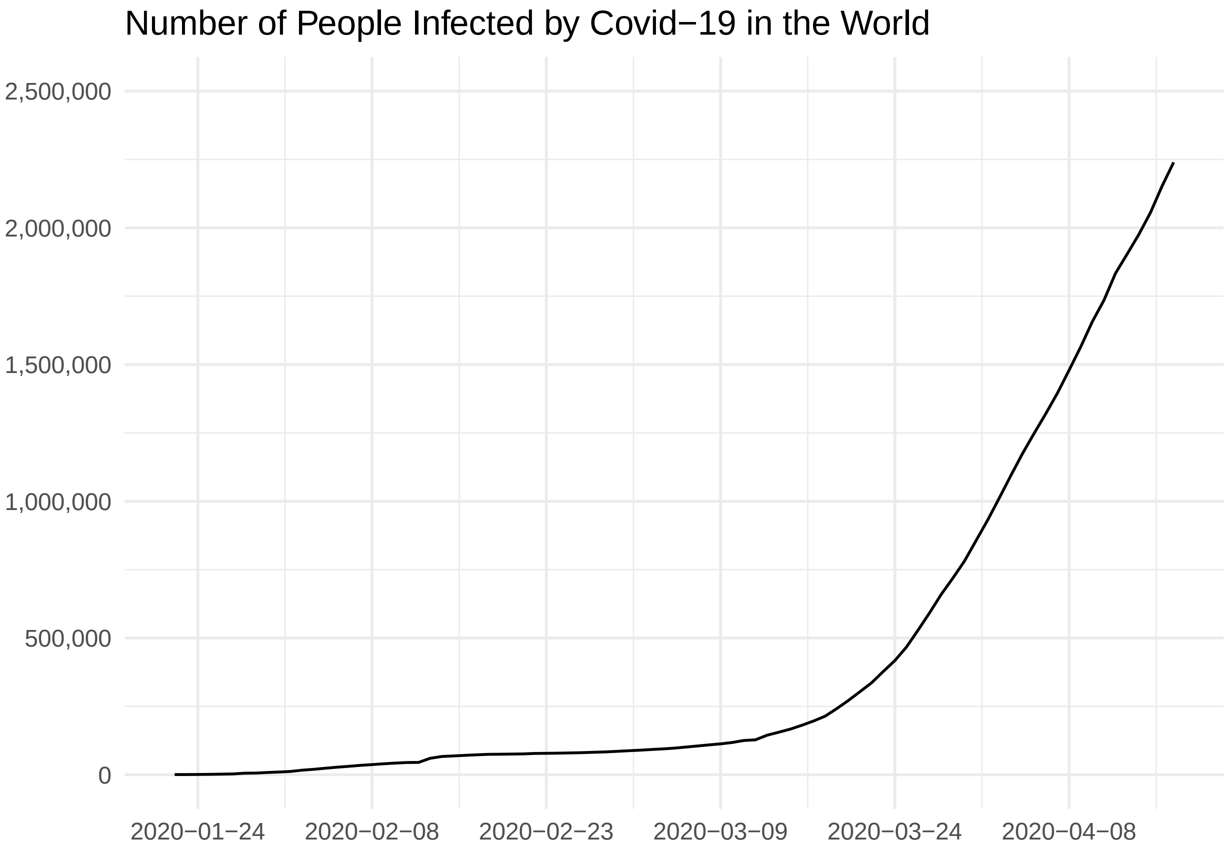
In this report, we use the Johns Hopkins dataset (also uploaded in the current repository) for the global overview and the data from The COVID Tracking Project for understanding the development in the US since it has testing information. We also use US states population data (uploaded in this repository) in order to understand the spread and testing of the virus from the per capita perspective.

This report is written with the data as of April 18th, 2020.

Overview of the Spread of Covid-19

Covid-19 is a Global Pandemic

Covid-19 began spreading in China around the end of 2019 and continued to spread globally with around 2240,000 people infected by the disease. The figure belows show the overall trend.



Globally, the following countries and regions are the hardest-hit places. [1]

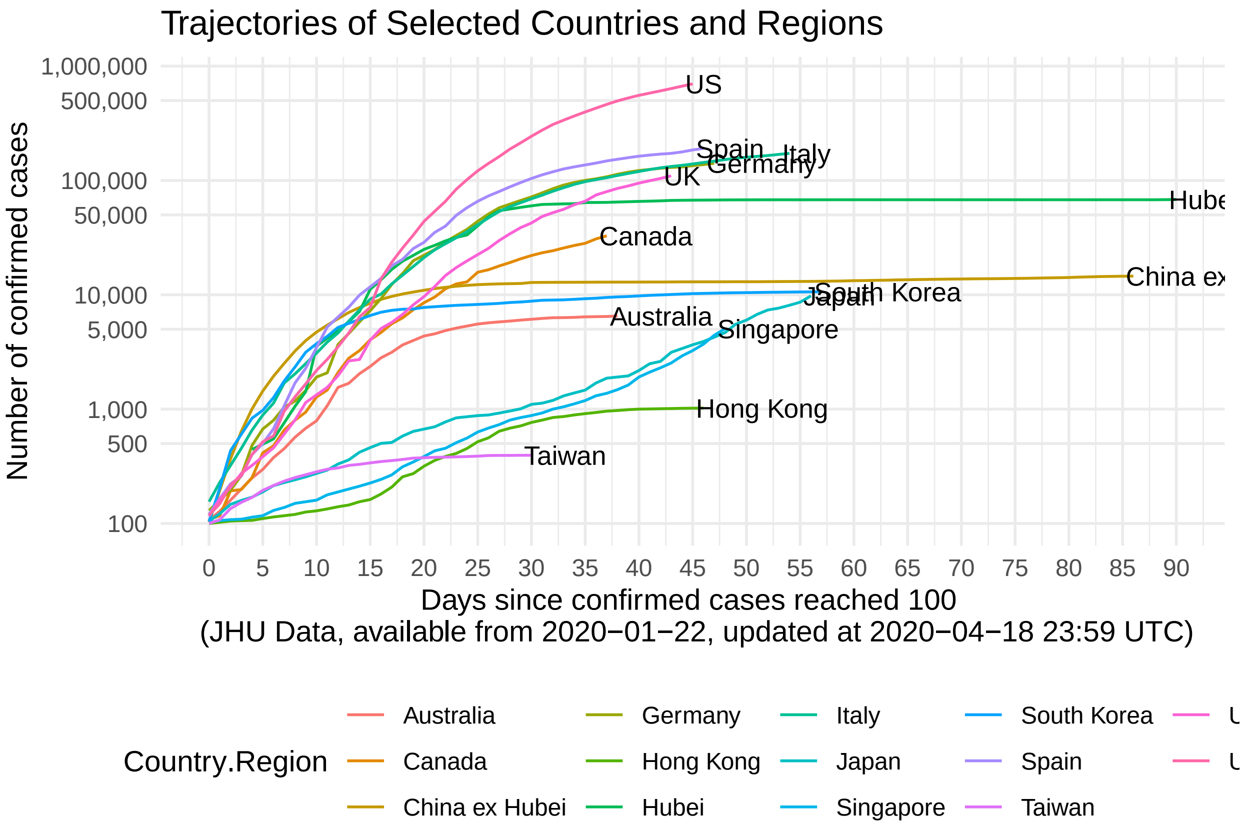
```
## # A tibble: 10 x 2
## # Groups:   Country.Region [10]
##    Country.Region  cases
##    <chr>           <int>
##  1 US             699706
##  2 Spain          190839
##  3 Italy          172434
##  4 France         149130
##  5 Germany        141397
##  6 UK             109769
##  7 Iran            79494
##  8 Turkey          78546
##  9 Hubei           68128
## 10 Belgium         36138
```

The following figure shows the trajectory of the spread of Covid-19 in some selected countries and regions. In particular, for each place, we define the date when the number of confirmed cases of Covid-19 reached 100 as the date of the "outbreak" and plot how the cumulative number of confirmed cases evolves after the outbreak.[2]

It seems that many Asian places including China, South Korea, Hong Kong and Taiwan has controled the situation roughly 30 to 40 days after the outbreak. The disease is spreading in Japan and Singapore at a somewhat controlable rate. The spread in rest of the countries in the figure is very concerning, despite that the growth starts to slow down.

[1] Notice that we treat Hubei Province and the rest of China separatedly in our report.

[2] We set the outbreak of Hubei Provence as Jan 19. While data is not available from JHU before Jan 22, we have checked from other data source that the number of confirmed cases has reached 100 for Hubei on that day.



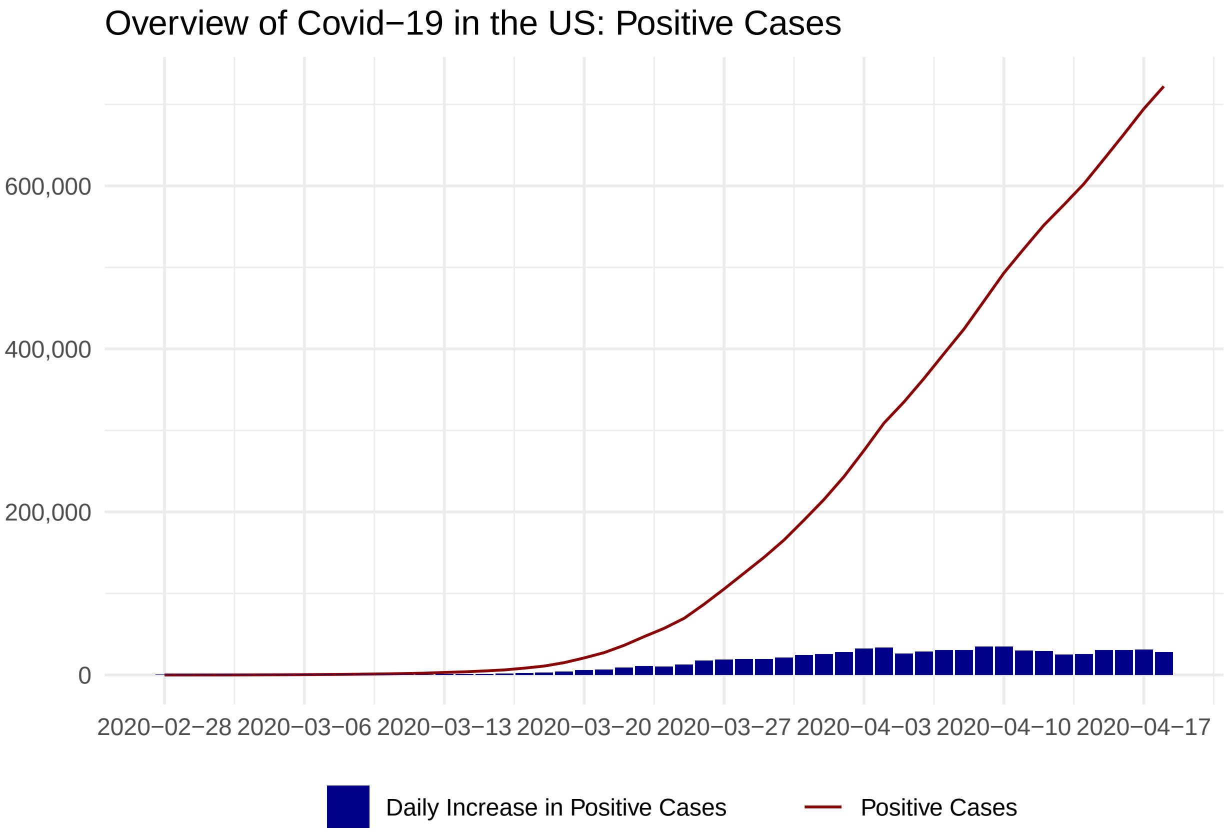
We emphasize that the number of confirmed cases in each country is affected by its testing policy and capacity, which are not uniform across the world. Moreover, countries with similar total number of confirmed cases may differ in the severity of the spread of Covid-19, due to the difference in total population and/or population density. As such, while it is tempting to argue a country is more efficient in containing the virus than another country, this argument is unfortunately inaccurate without a deeper dive into the data.

Spread of Covid-19 in the US

Now we move onto the US data. Currently, there are about 722,000 confirmed cases of Covid-19 in the US.

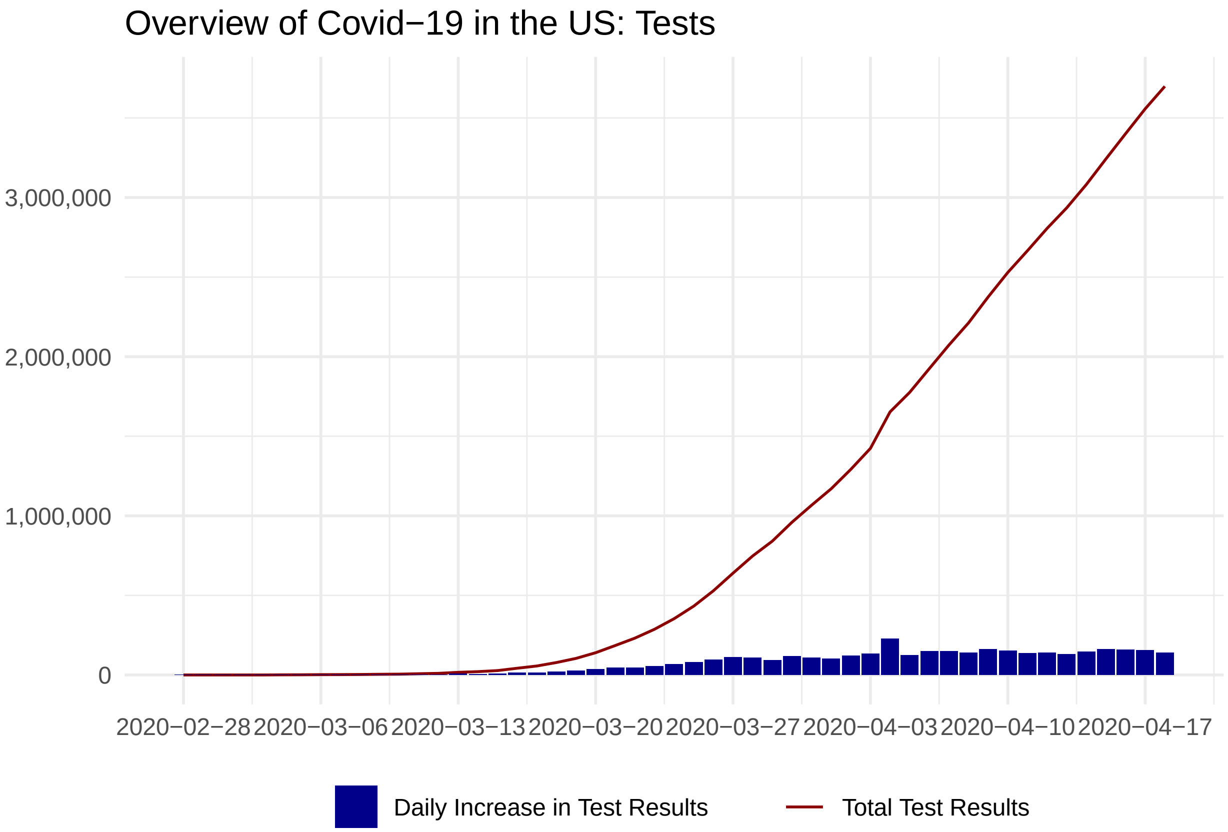
The figure below shows the dynamics of the spread in the US. The situation worsens rapidly in late-March, with the number of cases growing at the exponential rate (red curve). On the other hand, growth began to stablize in April. While a daily increment of about 25,000 cases is still concerning (blue bars), it does not continue to increase.

The question remains whether the stable growth reflects the fact that the virus has been controled or that insufficient tests has been performed. (Again, no one is confirmed to be infected without being tested.)



The figure below shows the cumulative number of Covid-19 tests performed in the US from the outbreak (dard red curve), together with its daily increments (blue bars).[3] One can roughly see that the number of tests grows at the exponential rate from mid-March, followed by the linear rate in the few week. Therefore, claiming that we have controled the spread of the virus from the slower growth rate in the last figure is not immediately warranted.

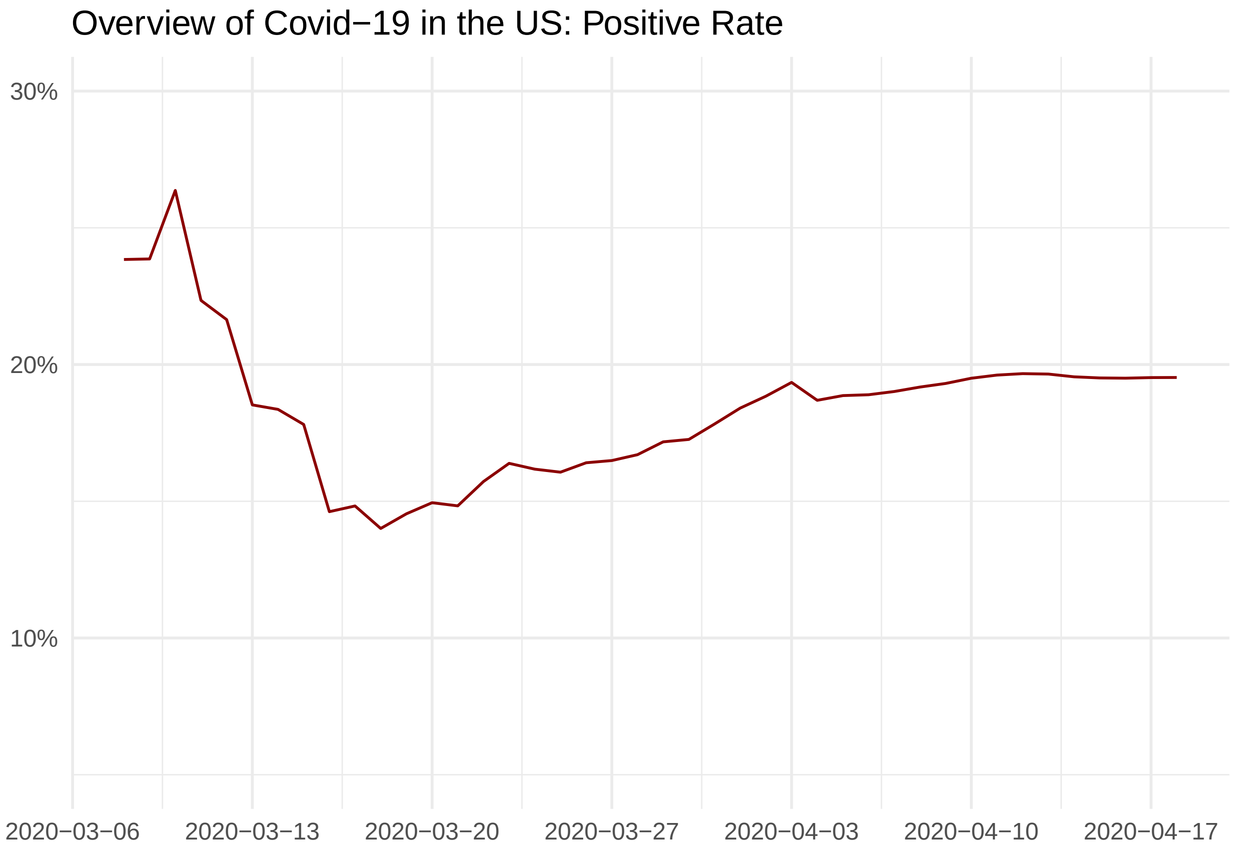
[3] Tests with pending results are excluded.



One metric, while it is not a perfect one, to measure if there are enough tests performed relative to the severity of the spread of disease is the positive rate, which is the percentage of people with positive test result among those tested for the virus. That is, positive rate = number of positive results / total test results. Both the numerator and the denominators are cumulative, meaning that this metric puts more emphasis on the recent situation than the past.

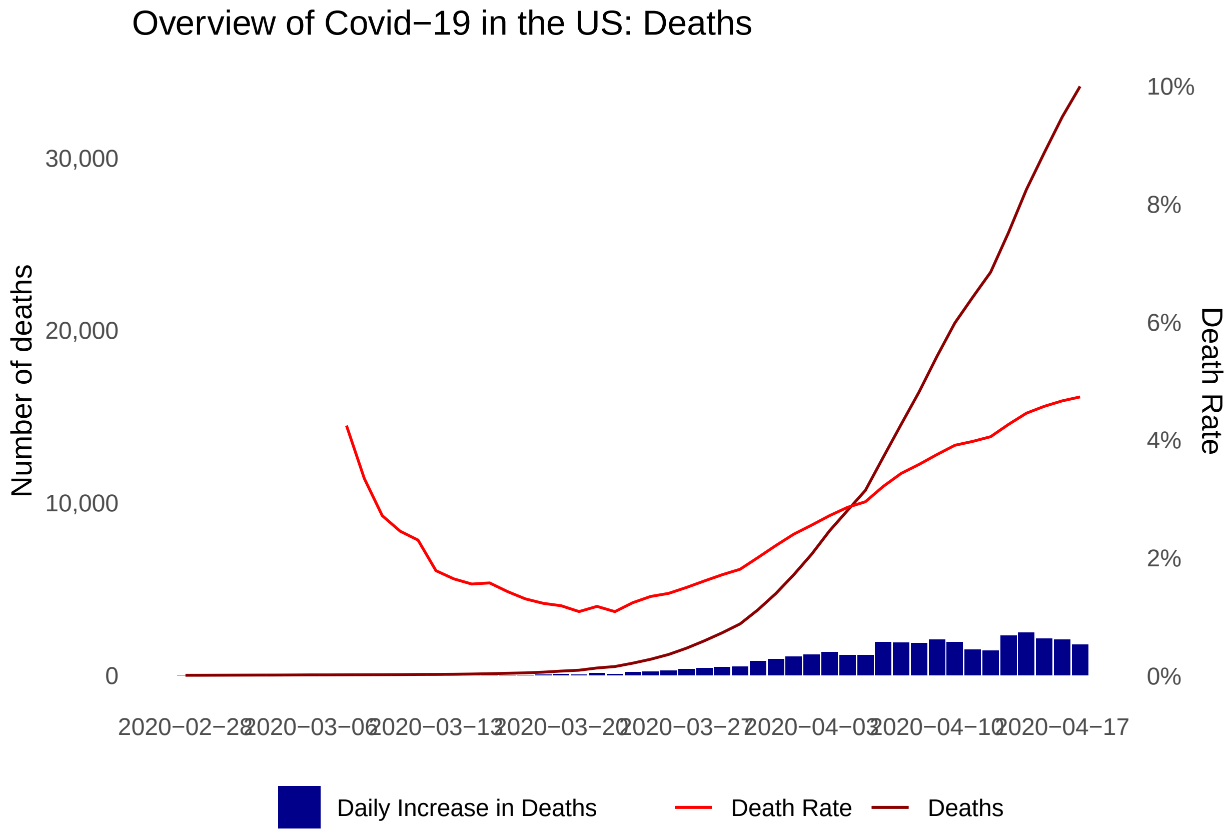
Persumably, only those who have symptoms similar to Covid-19 and the close contacts of infected people are tested for the virus. Positive rate is higher when tests are reserved for people with more severe symptioms or when contact tracing is performed less agressively. Either case suggests an insufficient testing capacity relative to the spread of the disease.

The figure below shows how the positive rate varies in the US after the outbreak. It starts from over 20% and decreases to the lowest level of 14% in mid-March. After that, the positive rate grows up to the current level of about 20%. This suggests that the testing capacity of the US is still inadequate relative to the spread of Covid-19. It also suggests again that we cannot directly claim that we have better control of the disease. At least, there is not enough evidence to make this statement.



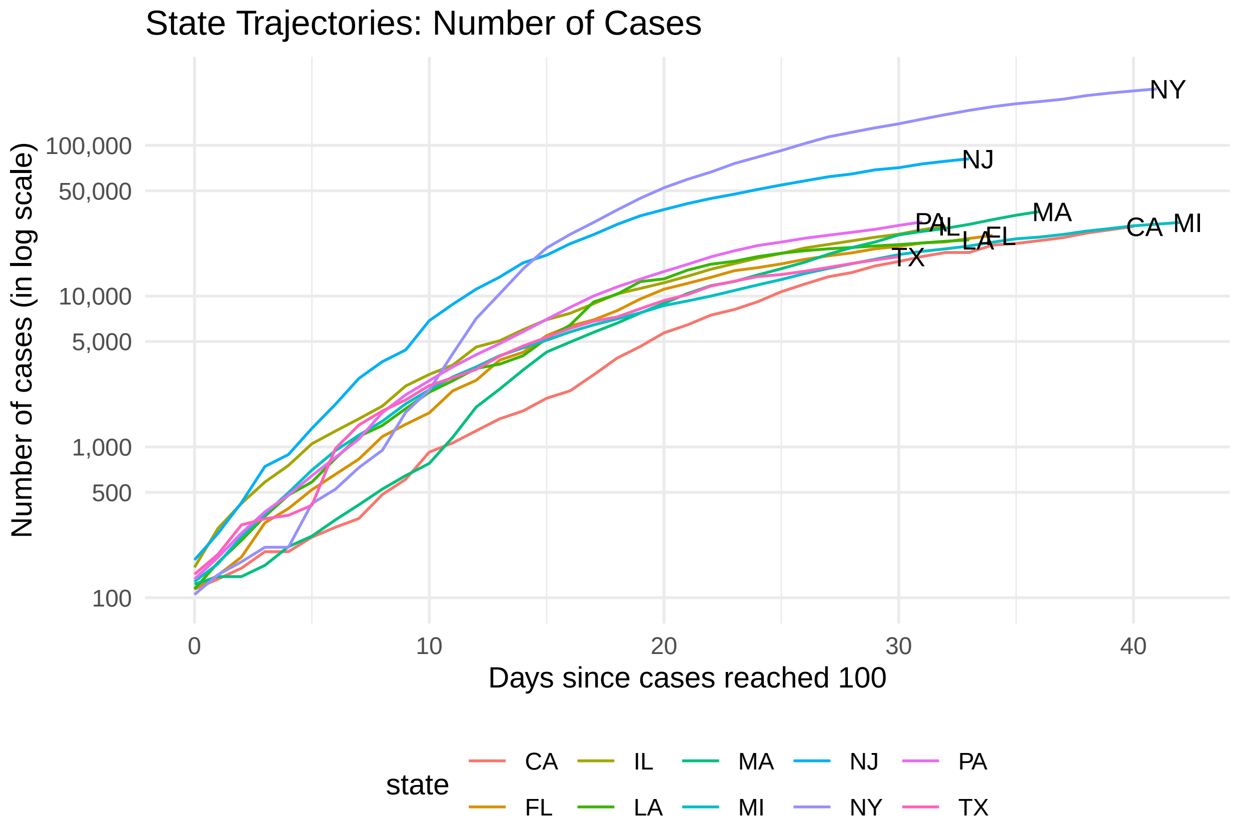
While postitive rate of Covid-19 tests is one way of telling whether the slowdown in growth rate indicates the spread has been effectively controlled, another way is to analyze the number of deaths instead of number of positive cases. Admittedly there could be people died of Covid-19 without begin confirmed as a Covid-19 death. But presumably, the states prioritize testing people with severe symptoms. Therefore, the number of deaths is affected by the testing policies to a less degree, compared with the number of positive cases.

The figure below shows the trajectory of the number of deaths in the US (dark red curve), together with its daily increments (blue bars) and cumulative death rate (light red curve). The high death rate at the beginning may be caused by insufficient tests. However, it is not clear why the death rate begins to increase again from its lowest point at around March 20th. We hope this is not caused by the overwhelmed health system. However, when this is true, there should be a constant "natural" death rate of Covid-19. The observed rising death rate may suggest again that may people infected by the virus are not tested.



US State-Level Analysis

We visualize the trajectory of the spread of Covid-19 for the top 10 states in terms of total number of cases in the figure below. NY, which is the state with the most cases of Covid-19, has 236732 people contracting the virus. Its neighboring state, NJ, has a similar trajectory. The trajectories of the rest of the states are similar.



Recall that we have argued above that the number of positive cases can be influenced by the testing policies and capacity, which vary across the states. We have also discussed about two approaches to understand the spread of the disease that mitigate such influences: focusing on positive rate from tests and focusing on deaths. We analyze the state-level data using both approaches.

Part 1: Number of Positive Cases and Testing Data

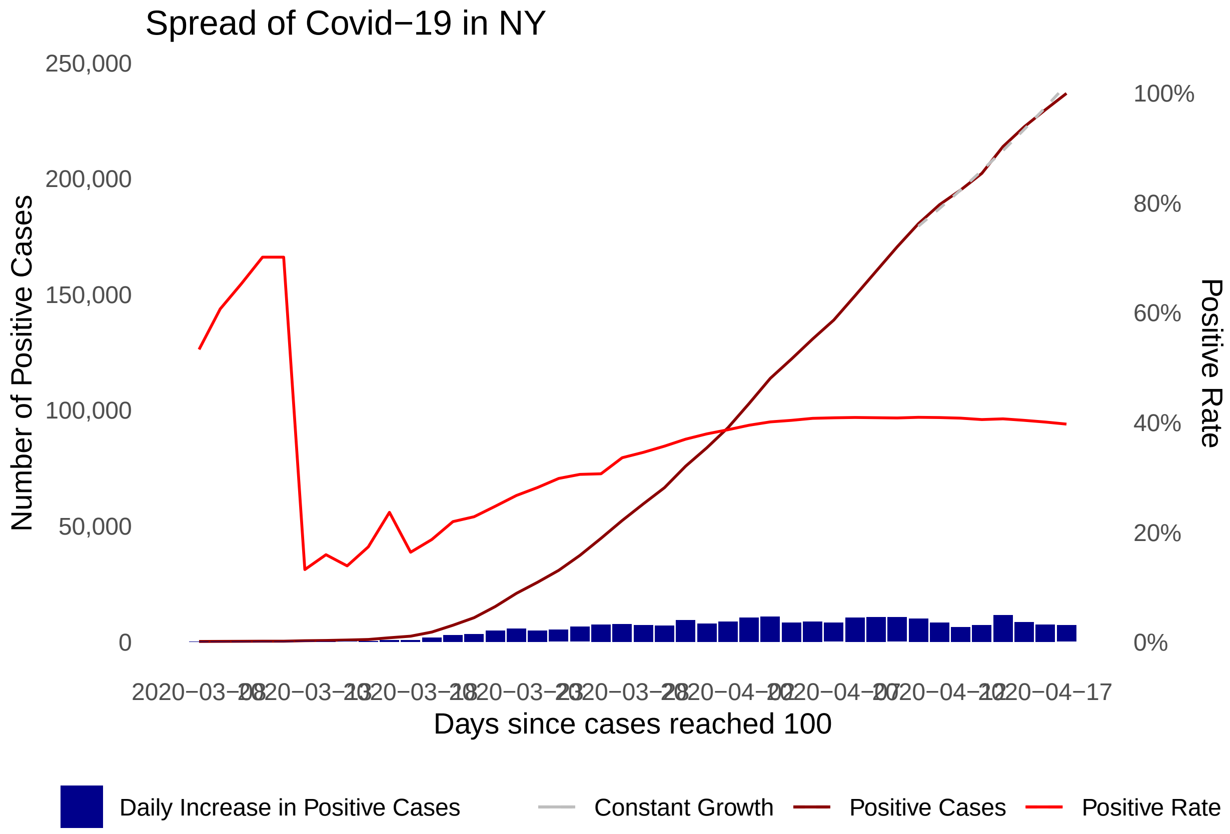
We study the trajectories of the following states in more details.

New York

New York is the state that is hit the hardest by Coronavirus. The figure below displays the dynamics of the spread of Covid-19 in NY after its outbreak. The dark red curve represents the number of positive cases while the grey dashed curve is the estimated number based on the average growth rate in a 5-day window between 3 and 7 days ago, assuming the constant growth rate. The purpose of displaying this grey curve is to facititate the quick visual comparison. For NY, its actual cases is below the extimated constant growth numbers, meaning that the growth in positive cases becomes slower.

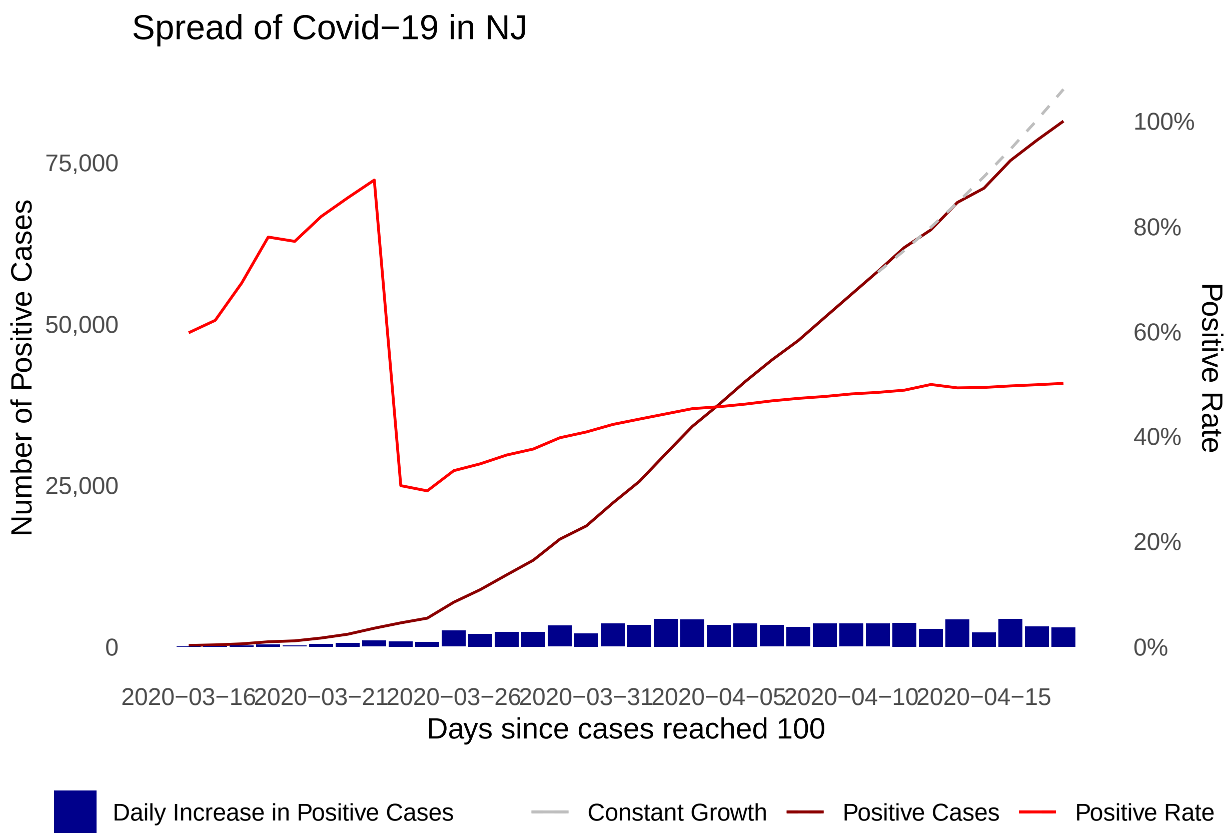
The dark blue bars captures the daily increments in the number of positive cases. One can also see that it keeps growing in March and becomes more stable in April.

The light red curve represents the trajectory of NY's positive rate. Recall that we have argued that the positive rate of tests measures the testing capacity relative to the severity of the spread. Since the positive rate stays at around 40% and decreases gradually recently, we tend to believe that the spread of Covid-19 becomes truely slower in the past week.



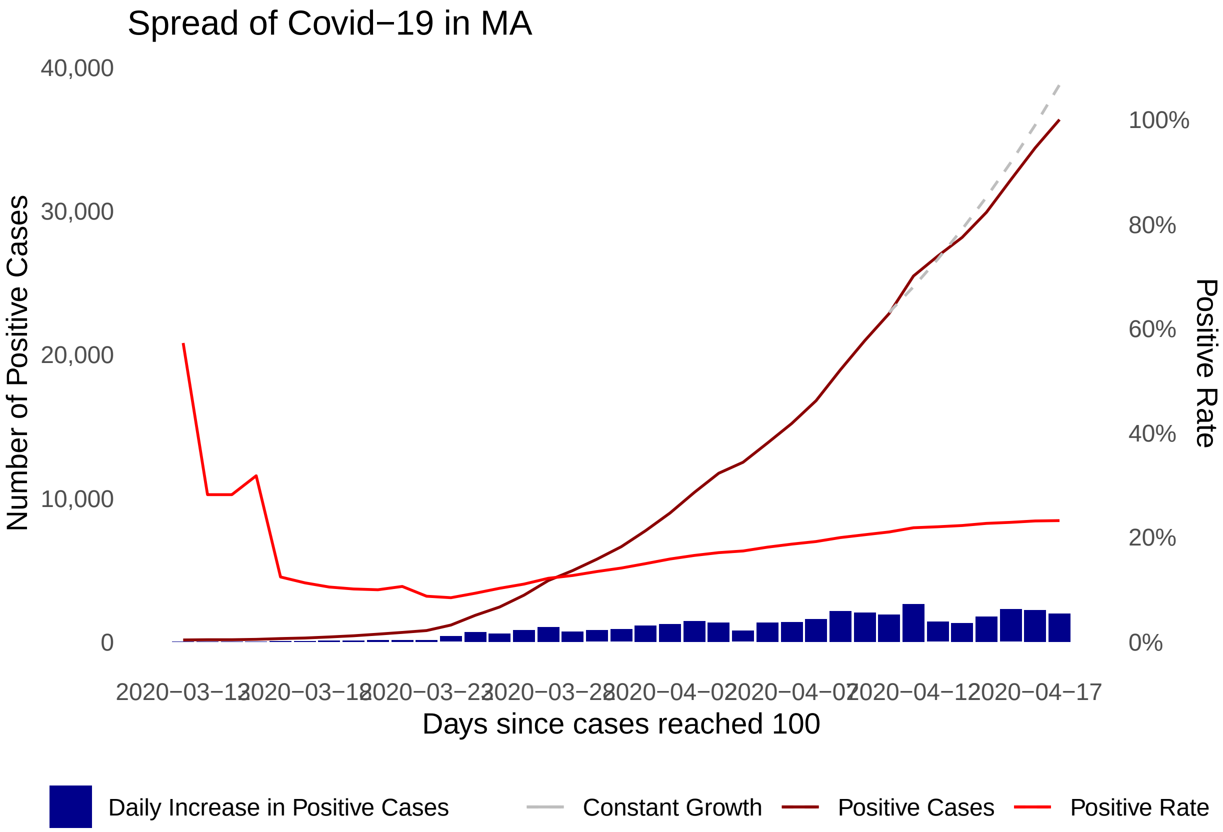
New Jersey

The situation in NJ is different. Testing capacity is not growing fast enough: Positive rate of Covid-19 test rises to about 50%. While the red curve of positive cases lies below the estimated numbers assuming constant growth, we don't have enough evidence to claim that the virus is being controled.



Massachusett

The situation in MA is similar. The curve of positive rate suggests that testing capacity is not sufficient. While the red curve lies below the grey curve, we don't have enough evidence to argue that the spread is slower.



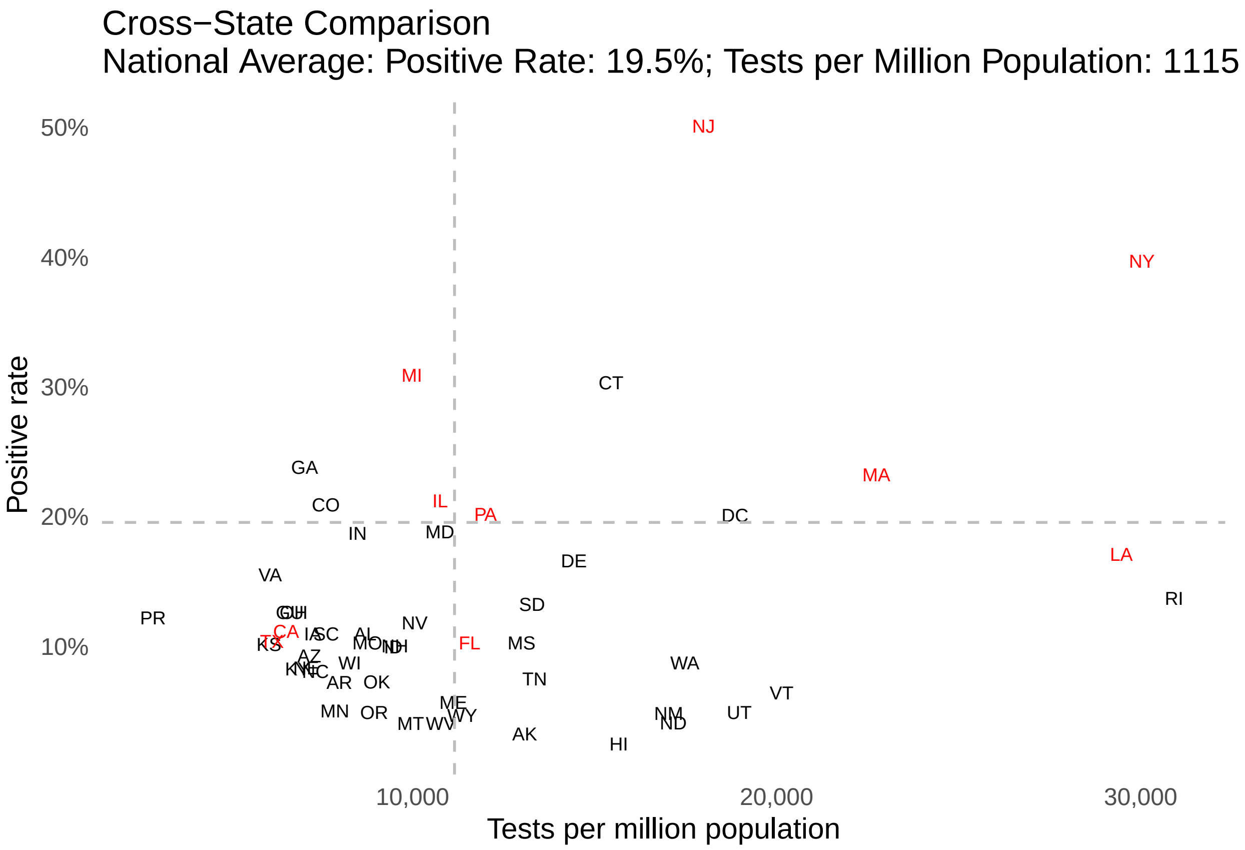
Cross-State Comparison

Since different states have different sizes of population. One metric to measure the sufficieny of tests is the number of tests per million population.

Both tests per million population and positive rate are related to measuring test capacities. The advantage of the formerone is that it is not affected by the testing policies that varies across states. However, the disadvantage is that it is not linked to the scale of the spread of the disease: We need more tests when the spread is more severe.

We argue that by using both metrics, we can make some simplecross-state comparisons, which is demonstrated by the figure below. We conjecture that each state prioritizes testing those who are more likely to be infected by Covid-19, including symptomatic patients as well as close contacts of infected people. When two states have performed the same number of tests per million population, their tests should cover the groups of people who are equaly likely to be infected. Therefore, the comparison of the positive rates between such two states should coincide with the relative severities of the spreads among the people with high risk, which is again closely related to the relative severities of the spreads in the states.

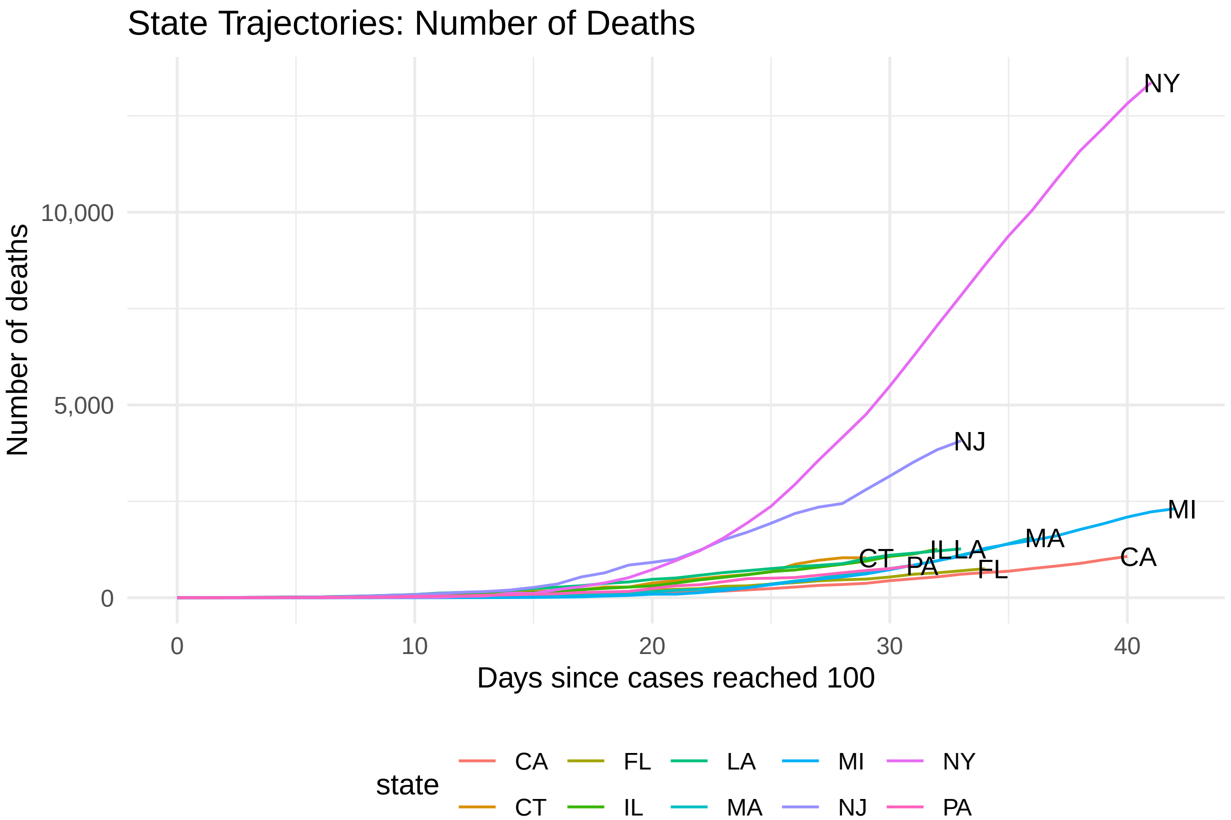
Based on this logic, we plot the figure below. Each state is places in the figure according to its per million population tests and positive rate. The top 10 states with the most cases are in red. The figure reveals, for example, that the spread is more severe in NY than LA, that it is more severe in NJ than DC, and that it is more severe in MI than IL.



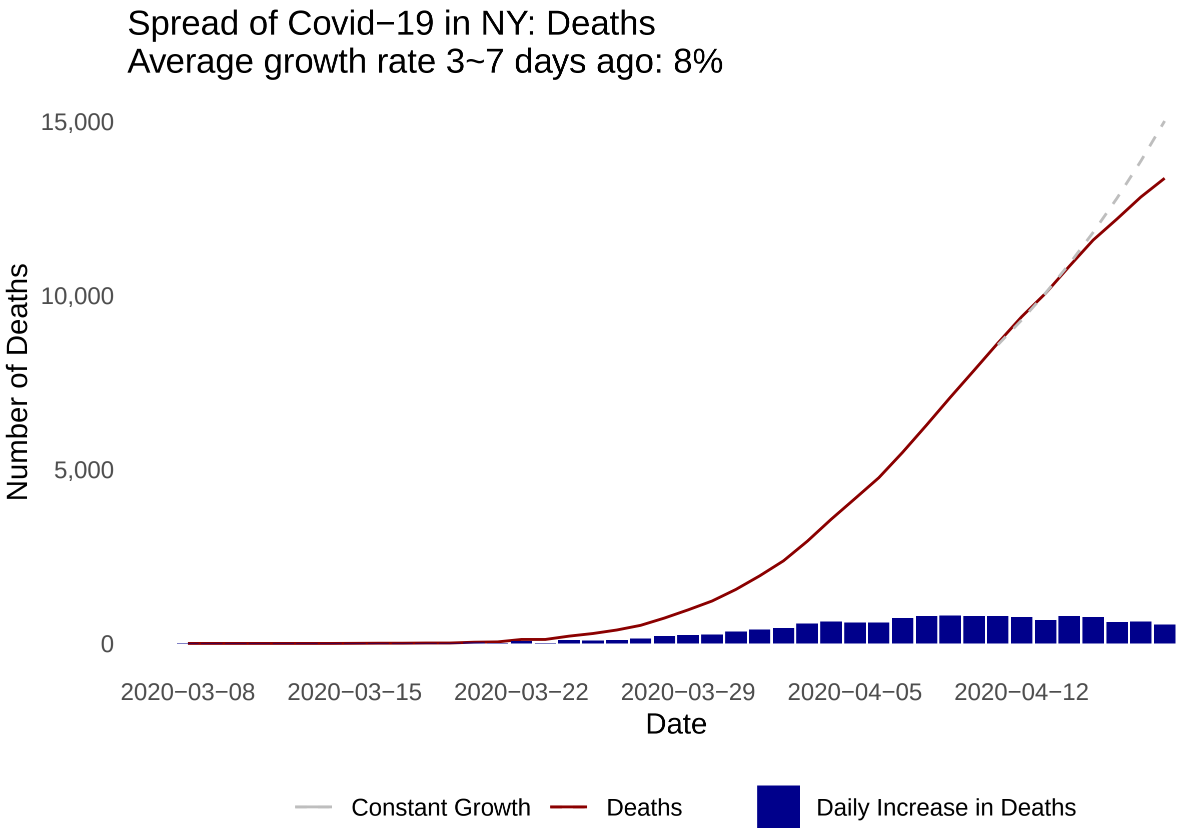
Cross−State Comparison
National Average: Positive Rate: 19.5%; Tests per Million Population: 1115

Part 2: Number of Deaths

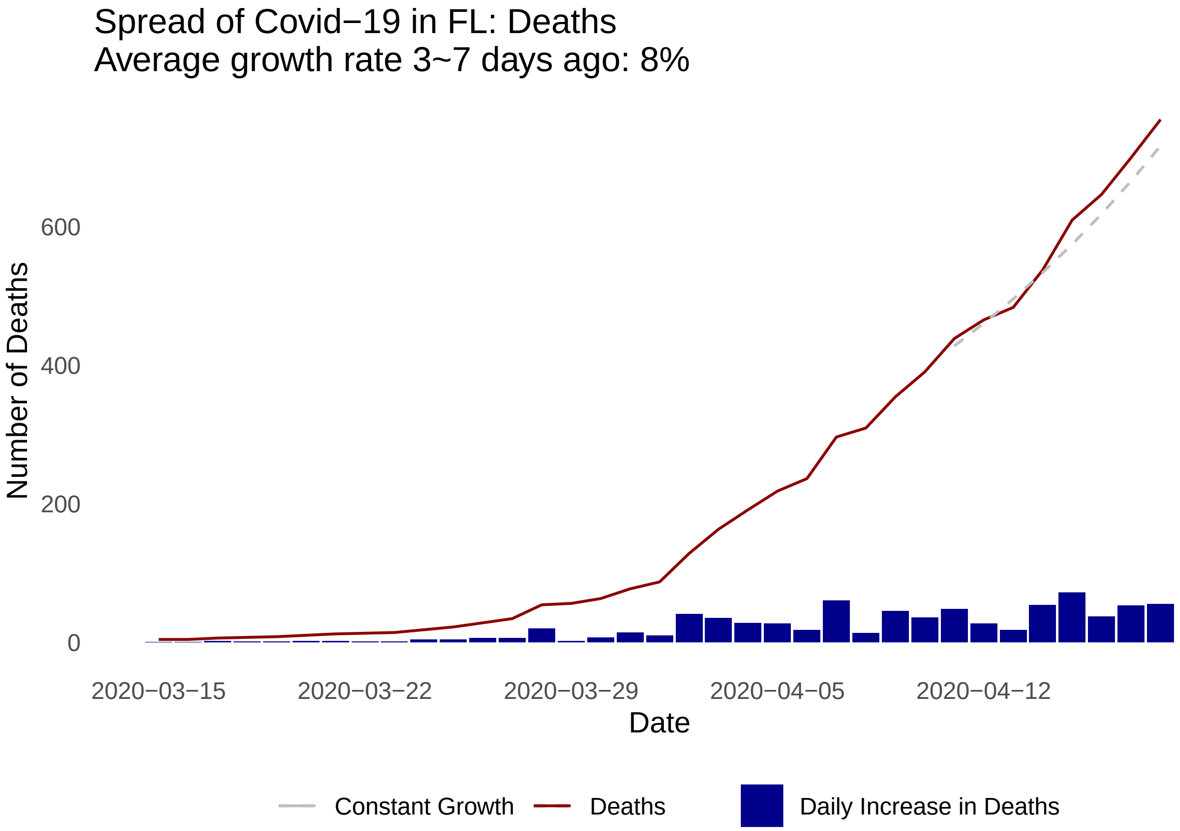
We now move onto studying the number of deaths. The figure below displays the trajectories of deaths of top 10 states after the outbreak. The trajectories of NY and NJ are very different from the rest. If one believes that the health systems of NY and NJ are not overwhelmed by the number of patients, this graph seems to suggests that the "real" outbreaks for NY and NJ are about 10 to 15 days earlier than the ones defined here – shifting the curves for NY and NJ to the right by 10 to 15 days, their trajectories are comparable with other states.



We plot the trajectory of deaths for NY in the same way as we did for positive cases. Since deaths is a more reliable measure of the spread of the disease than positive cases, we get the same conclusion that the virus starts to become under control in NY recently, since the red curve of deaths lies below the grey curve of the estimates assuming constant growth.

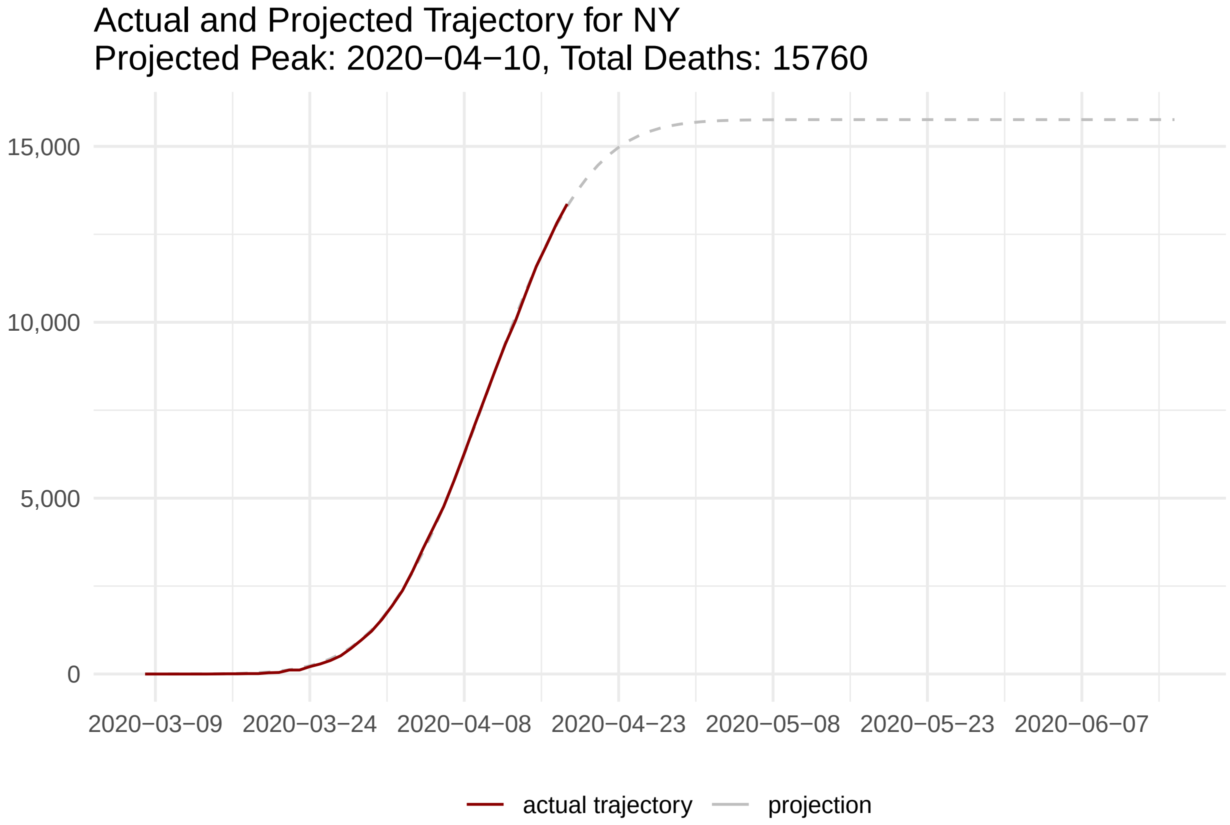


The figure below is the trajectory of deaths in FL. The growth does not seem to have become slower recently.



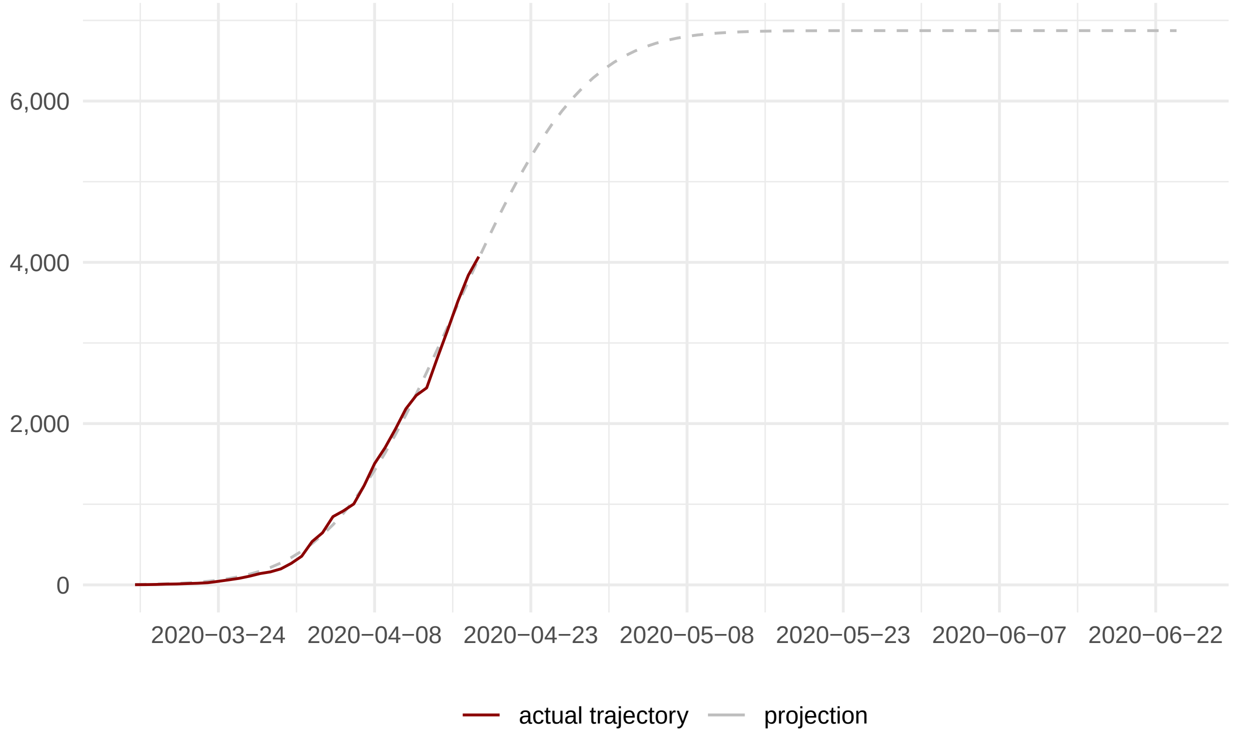
Projection of Deaths Curve

IHME predicts the development of Covid-19 based on deaths data. There key assumption is that the daily incremental deaths arranged by time have a bell shape. They rely on social distancing data together with deaths data to predict. Here we make predictions in a simplified way, since we do not have social distancing data – we directly fit the curve by approximate the cumulative deaths trajectory using shifted and scaled CDF function of normal distribution. It turns out that we replicate IHME's results quite closely. One can compare our predicted peak and total deaths with the ones projected by IHME. They are relatively close to each other. We demonstrate some examples below.

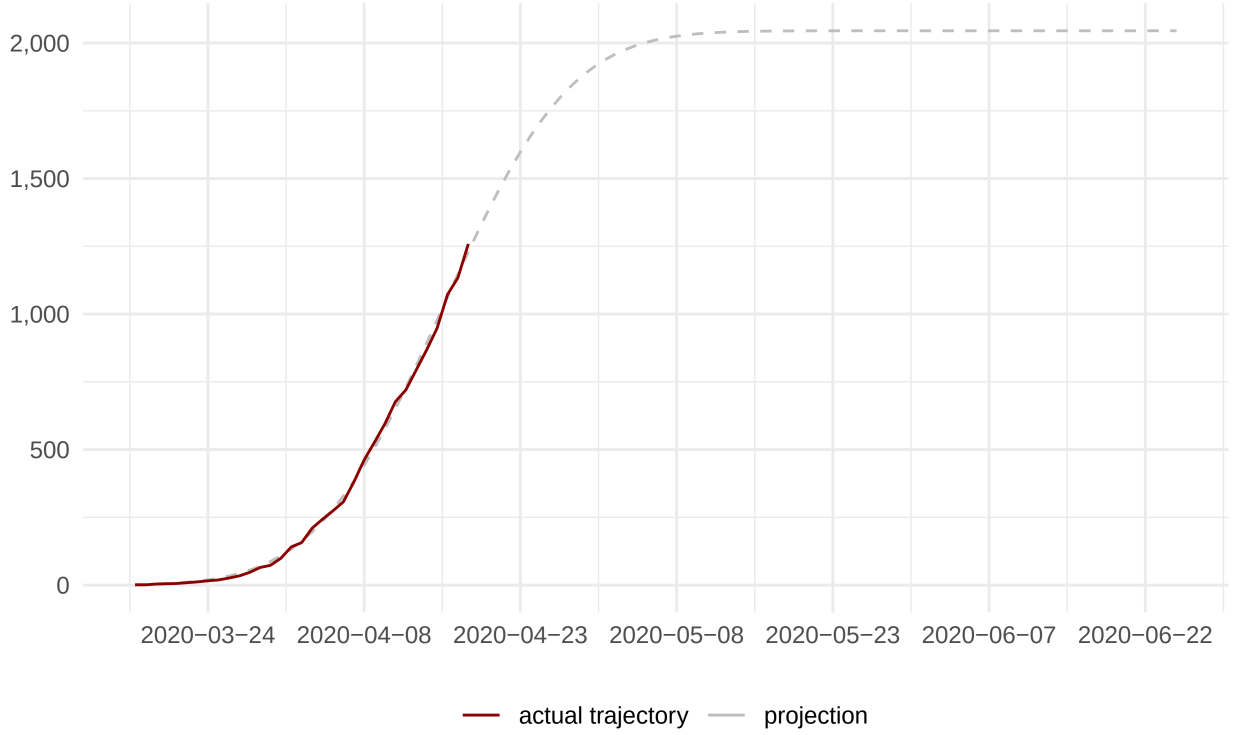


Actual and Projected Trajectory for NY
Projected Peak: 2020−04−10, Total Deaths: 15760

Actual and Projected Trajectory for NJ
Projected Peak: 2020−04−15, Total Deaths: 6873



Actual and Projected Trajectory for IL
Projected Peak: 2020−04−15, Total Deaths: 2045


actual trajectory
projection