1 The Waves of the Epidemic COVID-19

1.1 Summary

This study investigates successive waves of the ongoing COVID-19 diseases in Maharashtra State, New York, Belgium and London by setting up the deterministic susceptible-infected-removed (SIR) model. Based on the analysis and results, Omicron has higher transmission and removal rate than Delta and Alpha variants. While the transmission and removal rate of Alpha and Delta is region-based. It helps public health institutions to take precautions and control the spread the pandemic.

1.2 Introduction

The COVID-19 disease has become an ongoing pandemic since the end of 2019. It has evolved to many new variants which might have different characteristics. We are interested in the difference between COVID-19 variants, in particular the Alpha, Delta and Omicron variants and whether the transmission and removal rate is higher as the COVID-19 evolved based on the data given on Maharashtra State, New York, Belgium and London.

1.3 Method

As we are doing the analysis on the infectious disease COVID-19, it's reasonable to implement the deterministic susceptible-infected-removed (SIR) model of each variant:

$$S_t + I_t + R_t = 1 \quad \text{for all } t$$

$$\frac{dS_t}{dt} = -\beta S_t I_t \qquad \frac{dI_t}{dt} = \beta S_t I_t - \gamma I_t \qquad \frac{dR_t}{dt} = \gamma I_t$$

$$R_0 = \frac{\beta}{\gamma}$$

where S_t, I_t and R_t are the proportion of susceptible, infectious, removed individuals respectively in the population at time t. β is the transmission rate and γ is the removal rate. R_0 is the basic reproduction number that the expected number of infections to result directly from a single infection in the population.

1.4 Data Visualization and Result Analysis

Figure 1 displays the daily new cases including the waves and the peaks of the three major variants Alpha, Delta and Omicron for the four regions respectively. It seems like the waves of Omicron are sharper which means the transmission and removal rate are higher than the previous two variants in both New York and Maharashtra state, while the situation is not clear in Belgium and London. Therefor, we will be doing a deep analysis for each region.

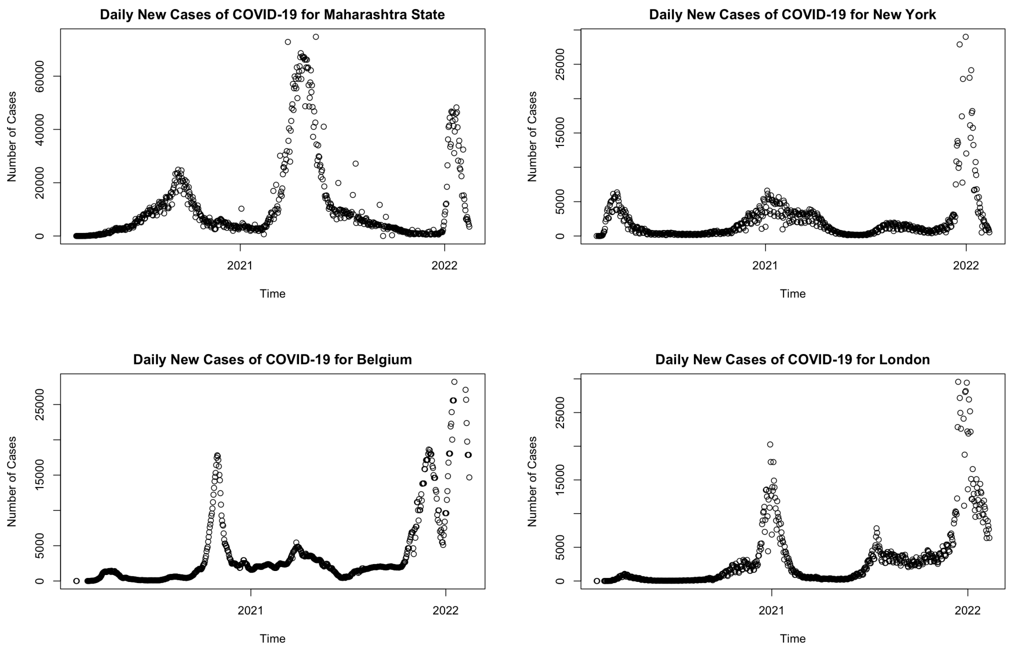

Figure 1: Daily New Cases of COVID-19 in Maharashtra State, New York, Belgium and London

1.4.1 Maharashtra State

Figure 2 shows the epidemic trajectory in Maharashtra State, it's clear that the black line (susceptible proportion) drop rapidly from around 0.44 to 0.12 in four months from March to June 2020 and the corresponding red line (infectious proportion) rises first then declines during that period. Also, there is a dramatic increase for the green line (removal proportion) which means that the patients would die or recover quickly. In contrast, the change of infectious and removal proportion are much smoother over six months, which explain the situation that the Alpha variant lasted longer as patients take more time to recover or die. Despite, the lines in 2(c) are also smooth, while the time period is only a month. The infectious proportion reaches to the peak in less than 15 days. We could also see that removal proportion rises speedily from 0.85 to 0.95, and one reason could explain that people were vaccinated during the time of Omicron so that infectious people can recover faster. However, the rapid infectious an removal rate will cause the medical system overloaded and infectious people can't receive proper treating. In addition, the comparison graph 2(d) of the three variants shows Omicron has the highest rate of being infectious and removed. The relatively lower removal rate probably contributes to the largest Delta cases as there would be longer time for infectious people to keep infecting others.

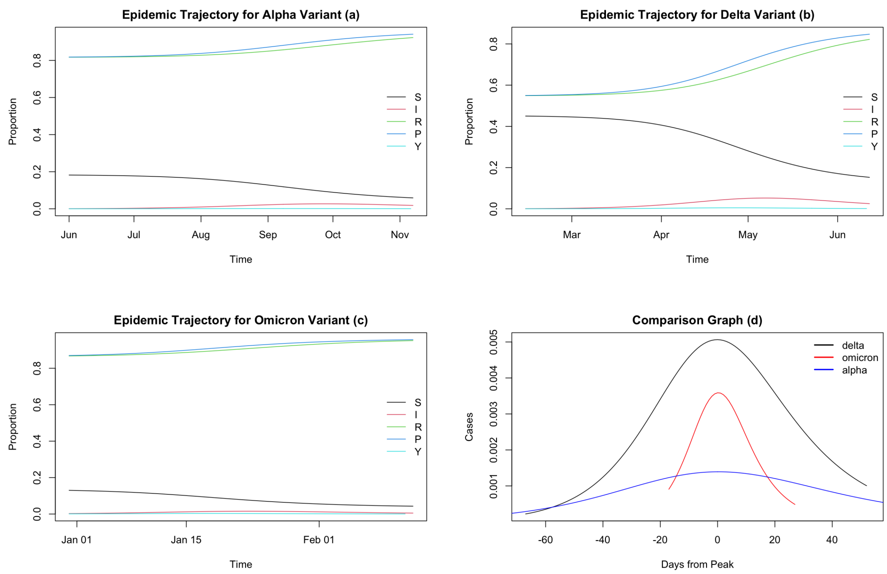

Figure 2: Epidemic Trajectory for Alpha, Delta and Omicron and the Comparison Graph in Maharashtra State

1.4.2 New York

Surprisingly, the change of infectious proportion for Delta is small in New York so the disease was not severe according to Figure 3, it might because that the government is taking effective regulations.

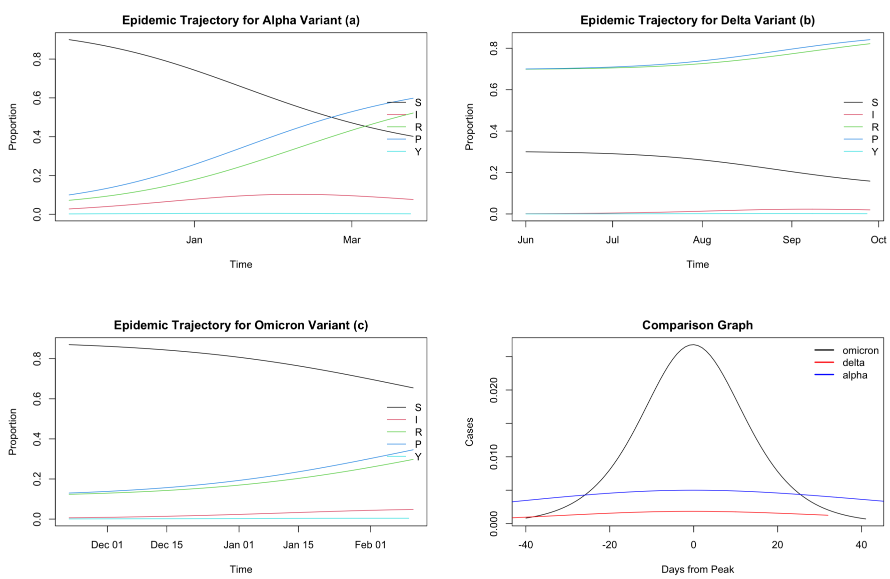

Figure 3: Epidemic Trajectory for Alpha, Delta and Omicron and the Comparison Graph in New York

Both the susceptible and removal proportions drops significantly during the time of Alpha. There are similar interpretations for Omicron in New York as in Maharashtra State, the infectious and removal proportions changes rapidly in a short period of time. The comparison graph implies that there is huge amount of Omicron cases and the infectious and removal rates for Omicron is much higher than the rest two.

1.4.3 Belgium

Figure 4 shows that all three variants have a sharp change in it's susceptible, infectious and recovery components in a short period of time. The infectious proportion for Delta changes from 0.18 to 0.6 in two month. In Figure 4(b), Alpha variant has a more rapid rise and drop compared with Delta. Despite Omicron has significant more cases than Alpha, while we cannot compare these two in in terms of transmission and removal rates as the two parabolas are almost parallel. There could be some problems in the Belgium data, as there is an unusual sharp point between the end of Delta and the beginning of the Omicron. More details and discussions will be given in the table part.

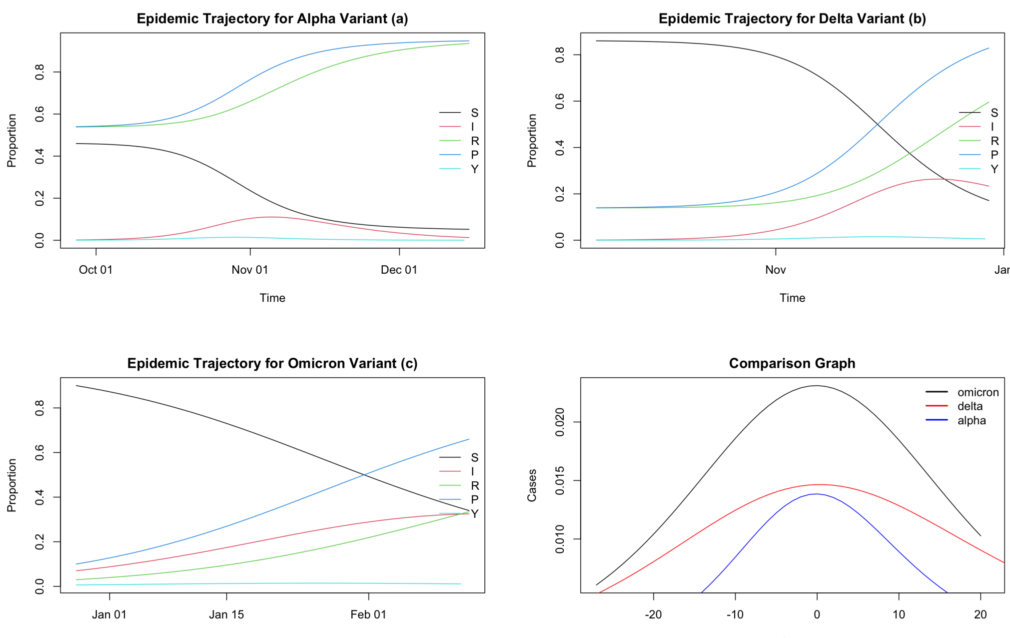

Figure 4: Epidemic Trajectory for Alpha, Delta and Omicron and the Comparison Graph in Belgium

1.4.4 London

It can be seen from Figure 5 that for London despite Omicron is on a short time basis, the proportions of infection and remove change much sharper than the rest two. The infectious proportion of Alpha changes quicker than Delta. It also reflects in Figure 5(d) that Omicron ranks the first, followed by Alpha and then Delta in terms of transmission and removal rate.

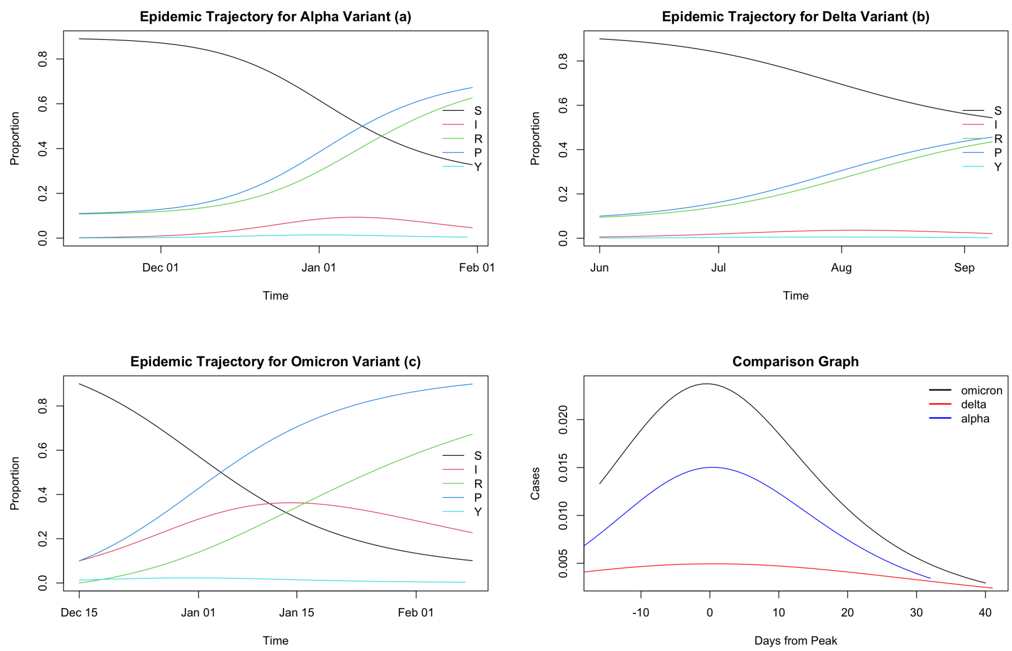

Figure 5: Epidemic Trajectory for Alpha, Delta and Omicron and the Comparison Graph in London

1.5 Conclusion and Limitations

Summary Tables of Transmission and Removal Rate of Four Regions

	Transmission Rate	Removal Rate
Alpha	0.480	0.045
Delta	0.340	0.086
Omicron	0.948	0.192

Table 1: Maharashtra State

	Transmission Rate	Removal Rate
Alpha	0.080	0.045
Delta	0.419	0.081
Omicron	0.530	0.085

Table 2: New York

	Transmission Rate	Removal Rate
Alpha	0.560	0.102
Delta	0.145	0.041
Omicron	0.102	0.031

Table 3: Belgium

	Transmission Rate	Removal Rate
Alpha	0.274	0.140
Delta	0.207	0.142
Omicron	0.343	0.244

Table 4: London

We could tell the values of transmission and removal rate directly from the Table 1,2,3,4. Omicron has the both highest transmission and removal rate among the three variants in Maharashtra State, New York and London which examines our interpretations for the graphs. The transmission rate for Omicron in Maharashtra is 0.948, which means that there is 95% chance for susceptible people in the population to be infected when contact with an infected person. The removal rate for Omicron in London is 0.244, which is the highest among all variants in all regions, so the Omicron would stay for the shortest time in London. While for Belgium, Omicron ranked the third, and Alpha has the highest transmission rate. It could due to the data inaccuracy and the Omicron is ongoing in Belgium with little data collected. The comparison for Alpha and Delta does not have a clear pattern based on the table, but the hypothesis for Omicron is correct that it has the highest transmission and removal rate which implies that Omicron would end most quickly.

2 Question 2: The Stochastic Process of the Epidemic

2.1 Summary

By doing simulations on the delta variant in Maharashtra State of no incubation, incubation of 2 days and incubation of 5 days, we proved the hypothesis that the incubation period would bring higher infection rate at one point.

2.2 Introduction

The deterministic SIR model can help us to model the epidemic trajectory for infectious diseases, while there is always reporting delays (incubation period) in the reality. For example, people may notice themselves infectious a few days later than the actual date. We aim to test the hypothesis that whether the incubation cause SIR models harder to identify by using the Markov chain Monte Carlo method to simulate the delays situation based on the delta variant wave in Maharashtra State.

2.3 Method

The stochastic version of the SIR model with $\lambda(t)$ is the intensity function of all events occurring:

$$\lambda(t) = \beta S(t)I(t) + \gamma I(t)$$

Noticed that the first infection may come from the outside population, the model would have a spark term:

$$P(\text{infection in } [t, t+dt)) = \beta S_t I_t dt + \tau(dt^2)$$

$$P(\text{removal in } [t, t+dt)) = \gamma I_t dt + \tau(dt^2)$$

β is a rate-of-infection parameter, γ is a rate-of-removal parameter, τ is the rate-of-infectious coming from outside in other words new infectious arrive from outside with rate τ infections per person per fortnight. S_t is the number of susceptible at time t, I_t is the number of infectious individuals at time t, and dt is the time increment.

The penalized complexity prior for the parameters with no incubation are:

$$\beta \sim \text{Gamma}(0.002, 0.007^2) \qquad \tau \sim \text{Gamma}(0.01, 0.05^2) \quad \gamma \sim \exp(1)$$

When there is incubation period, the model becomes SINR, where N stands for the notification. The time from a person being infected to notification is incubation period (ρ^{INC}), and the time from notification to recovery is delay period (ρ^{DEL}), and they can be modeled as:

$$\rho^{\text{INC}} \sim EXP(\gamma^{\text{INC}}) \qquad \rho^{\text{DEL}} \sim EXP(\gamma^{\text{DEL}})$$

The penalized complexity prior for incubation are:

$$\beta \sim \text{Gamma}(0.002, 0.007^2) \qquad \tau \sim \text{Gamma}(0.001, 0.02^2) \qquad \gamma^{\text{INC}} \sim \exp(1) \qquad \gamma^{\text{DEL}} \sim \exp(1)$$

2.4 Result

Then we compute the simulations twice with 500 individuals for no incubation period of the delta variants in Maharashtra State with the transmission rate of 0.002, outside infectious rate of 0.001 and the removal rate of 0.086.

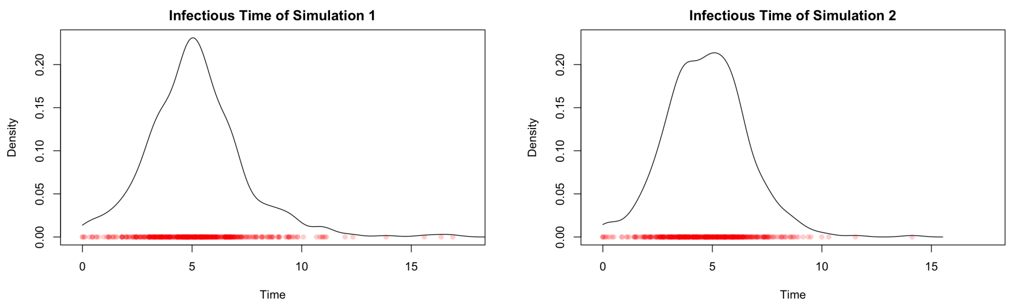

Figure 6: Density Plot for Simulations With no Incubation

Figure 6 shows the density plots for simulations without incubation and the red dots are the new infection. We could see that most new infection gathered at the middle-left of the time scale, and there are a few on the right time scale. We implemented four chains to examine the validity of the stochastic process, and the Figure 7 shows that the traces of four chains are tangling each other which are valid trace plots.

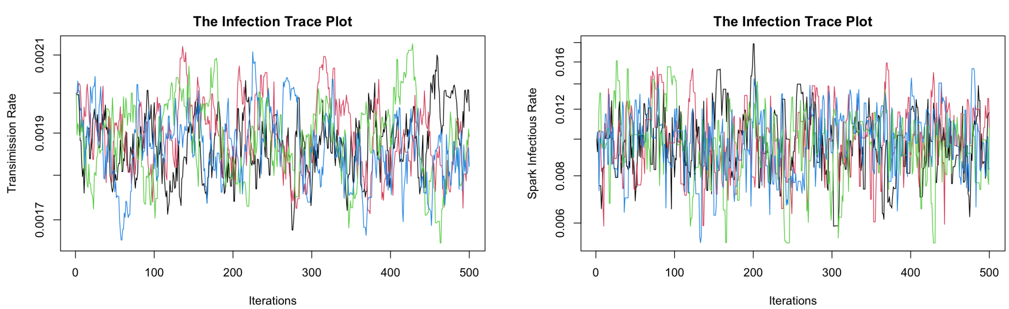

Figure 7: The Trace Plots for Simulation With No Incubation

We could roughly find the credible intervals for transmission and outside infection parameters in Figure 8. Furthermore, the transmission rate is between 0.0017 to 0.0019 and the spark infection rate is between 0.006 to 0.015.

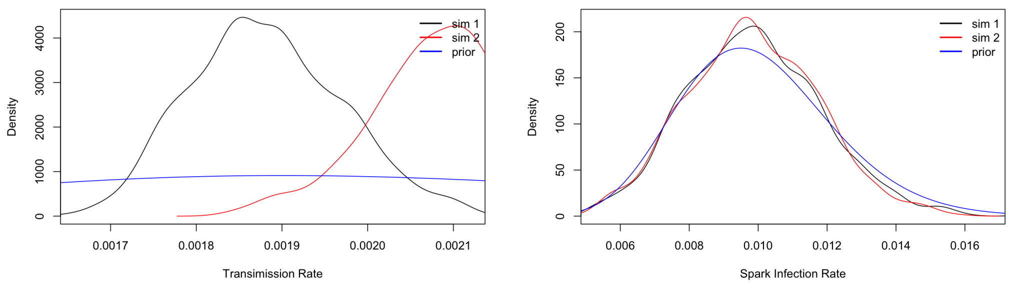

Figure 8: The Infectious Rate for Simulation With No Incubation

Then we will show the results for the incubation of 2 days and 5 days separately still by running simulations twice for each.

Figure 9 demonstrates the situation for incubation of 2 days. On the density plot, it can be seen that there are more new infections gather around on left of the time scale with no cases as time went. Also, the the two trace plots show good behaviors for us to keep computing.

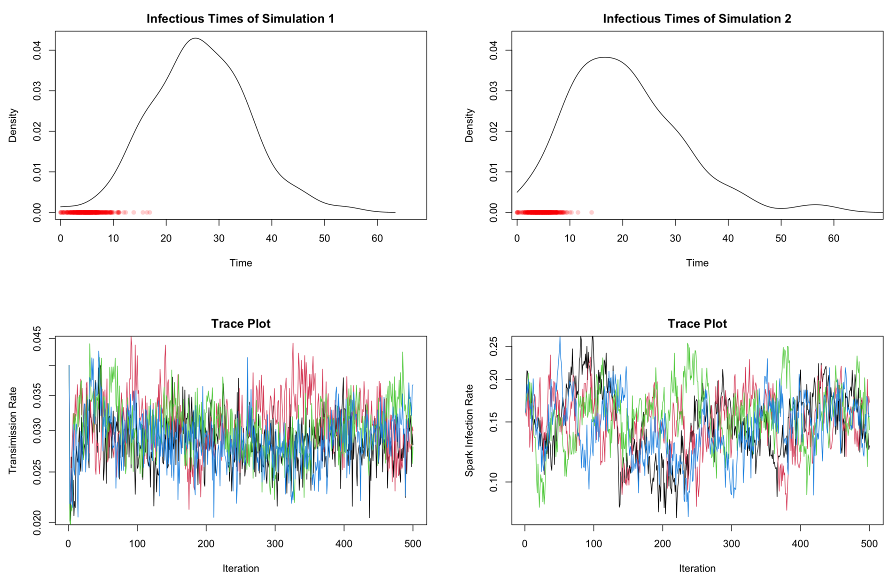

Figure 9: Density and Trace Plot for 2 Incubation Days

The Figure 10 shows that both the transmission and spark infection rate are larger than before. The credible interval for transmission is about from 0.025 to 0.040, and the spark infection rate is from 0.10 to 0.25.

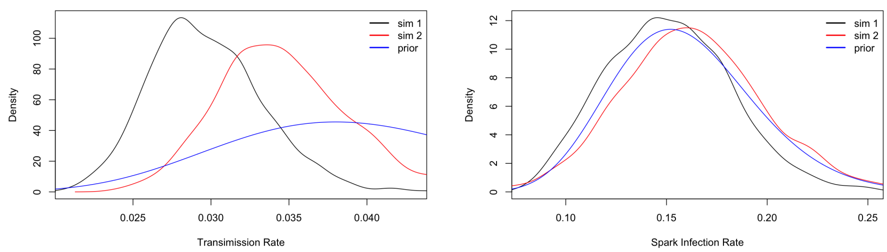

Figure 10: The Infectious Rate for Incubation of 2 Days

Still, the density plot for incubation of 5 days shows that most new cases are denser around the left side, and the trace plots are behaving good.

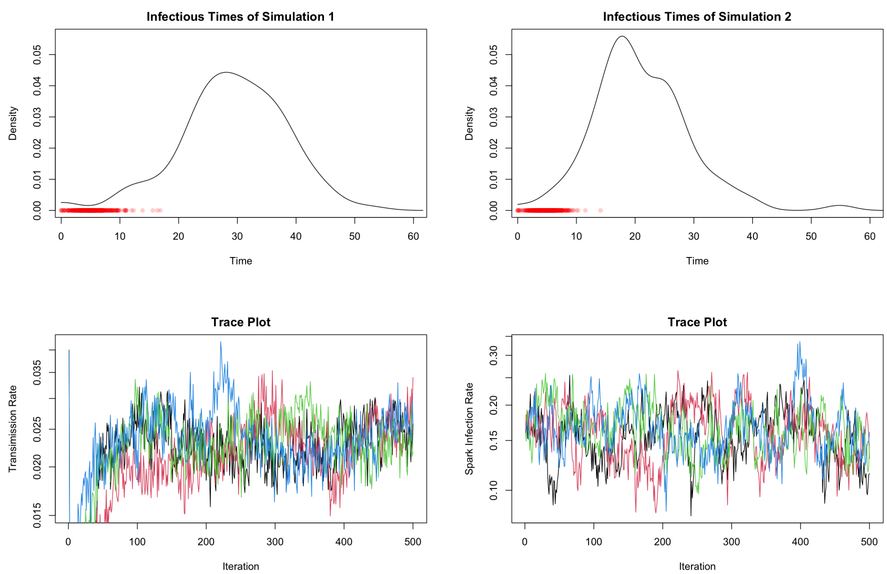

Figure 11: Density and Trace Plot for 5 Incubation Days

The transmission rate and spark infection rate increase again for 5 incubation days. The credible interval for transmission rate is from 0.020 to 0.035 slightly increase compared to 2 incubation days. The spark infection rate is from 0.10 to 0.30.

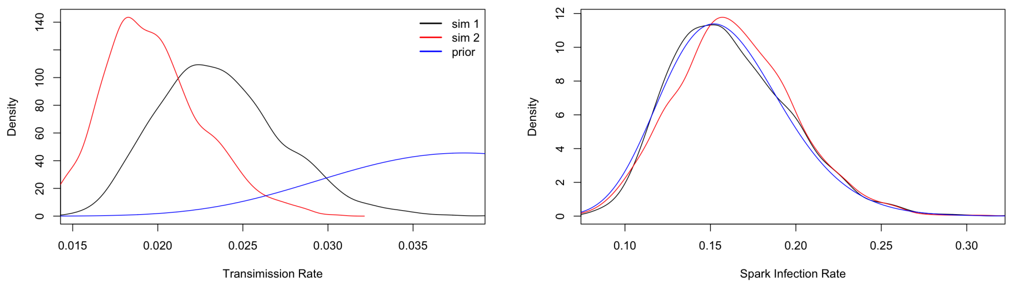

Figure 12: The Infectious Rate for Incubation of 5 Days

Therefore, we can conclude that due the increase of incubation period might bring to the problem for SIR models. There would be more rapid transmission rate that might lead to the scarcity of the hospitalization and medical care resources.