Epidemic modelling and the effect of public health interventions – Part I

In this analysis we shall fit a compartment model to COVID 19 outbreak data for India in the pre lockdown period and use simulations to explore the impact of lockdown on the epidemic and perform a what -if analysis for strategies for imposition and relaxation of the lockdown.

We shall use an extension of the SEIR model which includes the following compartments:

Compartment	**Functional definition**
S	Susceptible individuals
E	Exposed **and** infected, not yet symptomatic but potentially infectious
I	Infected, symptomatic **and** infectious
Q	Infectious, but (self-)isolated
H	Requiring hospitalisation (would normally be hospitalised if capacity available)
R	Recovered, immune from further infection
F	Case fatality (death due to COVID-19, not other causes)

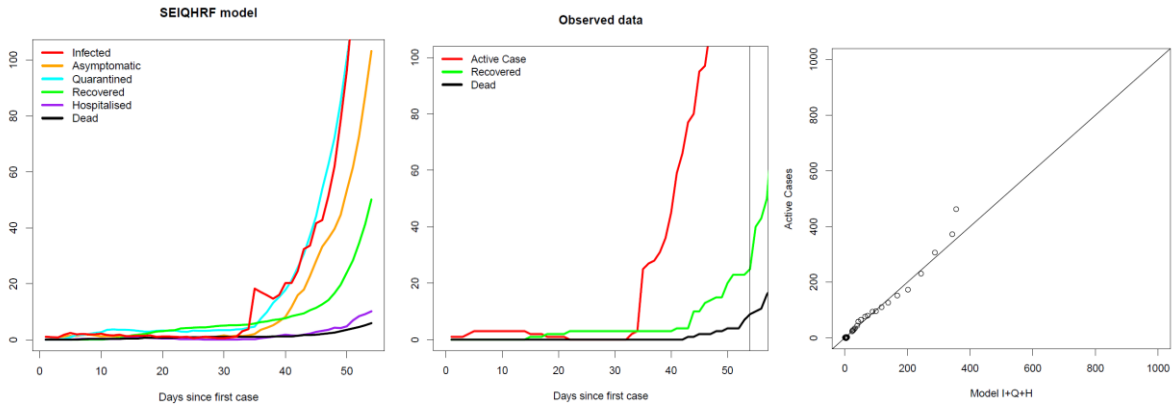
The resulting curves were validated with the observed data for India from https://ourworldindata.org/coronavirus-data for the pre lockdown period and the best fit was obtained to the observed case and fatality data by using the following set of parameters

- Number of exposure events per day between symptomatic infected and susceptible = 2 (low value as India started implementing screening and quarantine for suspected cases from mid January)
- Probability of passing an infection from infectious to susceptible =0.03
- Number of exposure events per day between asymptomatic and susceptible = 40 (relatively higher value as the testing rate was low)
- Probability of passing an infection from asymptomatic to susceptible =0.01
- Number of exposure events per day between quarantined and susceptible = 2

- Probability of passing an infection from quarantined to susceptible = 0.02
- Rate per day at which symptomatic infected enter quarantine = 1/5. (as the Indian government was both quarantining and advocating self quarantine from January)
- Available hospital beds for the susceptible whom each case infects = 40
- Daily death rate among susceptible = 7.3/1000/365 (based on CDR for India)
- Daily death rate among asymptomatic = 20/1000/365 (as they are probably in early stages of infection)
- Daily death rate among quarantined = 30/1000/365
- Daily death rate among infected = 30/100/365 (As deaths will occur in the H compartment. Note also that H denotes needing to be hospitalized and not necessarily hospitalised as all may not seek care or have access)
- Daily death rate among hospitalised = 80/365/1000.

Note that the model also includes two additional compartments corresponding to asymptomatic individuals and cases requiring hospitalisation which would put additional burden on the healthcare system. Of especial interest for this model is the E compartment of asymptomatic infectious whose behaviour over time can account for increased case numbers even after improvement in healthcare facilities for symptomatic cases.

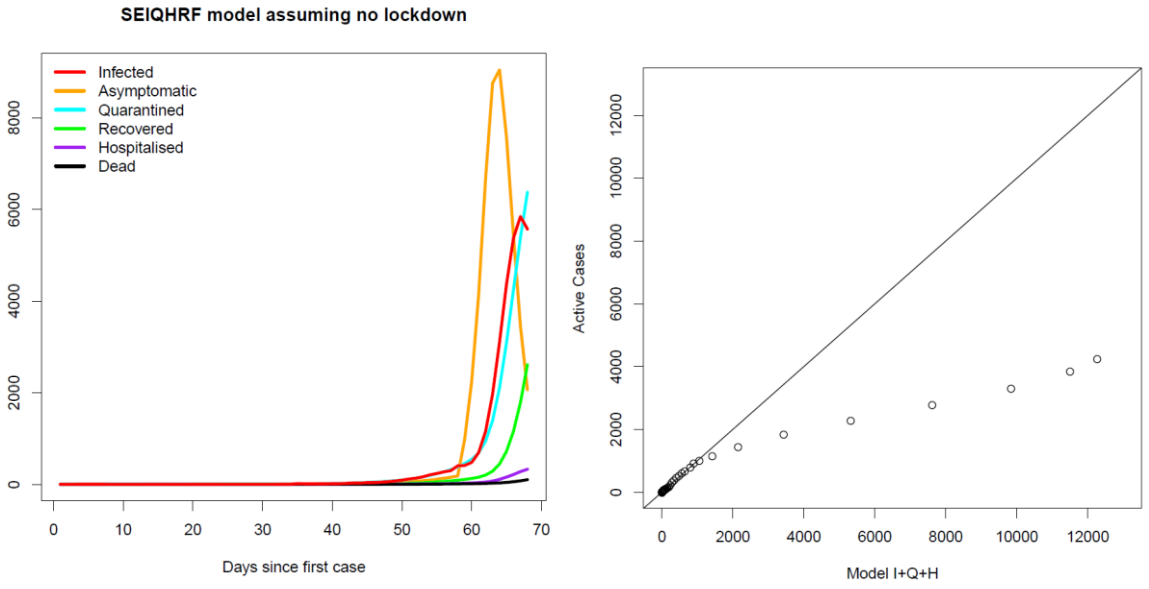
The figures on the next page present the epidemic curves from the fit for the pre-lockdown period in India. Time is indexed as starting from the date of the first confirmed case corresponding to January 30th, 2020. Fitting was done based on the extensions to the EpiModel package in R developed by Tim Churches (https://timchurches.github.io/blog/posts/). As initial confirmed cases largely corresponded to foreign travellers, each such case was used as the index case for infecting a network and the cumulative effect of the resulting transmission is presented below. Case specific data for India was obtained from www.coviv19india.org.



The above figure shows the predicted daily prevalences for the various compartments for the model, the plot of active , deceased and recovered cases for India pre lockdown and the agreement of the observed and model based daily case numbers. Note that the appropriate comparison is between the daily count of active cases and the sum of cases in the infected, quarantined and hospitalised compartments.

What if there was no lockdown and/or travel ban?

We shall next simulate from the fitted model to estimate likely case counts in the absence of a lockdown and a travel ban. We shall assume that infected travellers continue to enter India at the observed average rate over the pre lockdown period and observe the results until the first week of April.



The above figure shows the simulated case counts for the various compartments until the first week of April and a comparison of the model based predicted daily cases and the observed daily active counts .Note that the points in the second plot lie below the 45 degree line indicating that the active cases post lockdown are generally lower. This gives some preliminary evidence of the effectiveness of lockdown and travel bans.

Note also that the model output suggests an enormous spike in asymptomatic cases which are potentially infectious. This suggests that one reason for the effectiveness of lockdown is reduction in the contact between such individuals and the susceptible population.

If such a situation were to prevail until the end of May, the model estimates a total active case count of 45000 including 1300 fatalities.

Did the early intervention strategy work?

The above simulation does, however assume that India's early intervention of screening, contact tracing and quarantine is maintained throughout the period. Case numbers and fatalities have been far lower in India than in other nations of comparable population and the controversy regarding testing notwithstanding, this could be a potential alternative explanation for the low counts.

We next explored predictions for India assuming that the government had done nothing. The contact rate parameters between the various model compartments and the quarantine rate were adjusted to reflect this. The infection parameter was increased slightly to reflect the absence of public health information campaigns such as those promoting hand washing.

Had the government adopted no strategy to combat the epidemic, the model estimates that at the end of May, the model estimates that total active case count could be as much as 1076881 including 113151 fatalities.

What should we expect if lockdown is completely lifted?

We refitted the best fit SEIQHRF model to the case data using the case counts upto the first week of April. The effect of lockdown was incorporated into the model by reducing the contact rate parameters between the various

compartments. Relaxation of lockdown was modelled by restoring these parameters to their original values in the pre lockdown period. The earlier strategy of airport screening, contact tracing and quarantine was however assumed to continue.

For this situation, the total case count was observed to be 85000 with 1500 fatalities at the end of May.