SIDARTHE model of COVID-19 in Italy

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Project course in Scientific Computing 2020/2021

Introduction

Since December 2019, the outbreak of COVID-19 in Wuhan has been spreading rapidly worldwide. In the early stages of the COVID-19 outbreak, it is important to use mathematical models and combine small amounts and real-time updates of multi-source data to conduct a risk analysis of the outbreak and assess the effectiveness and timeliness of prevention and control strategies.
The common features of sudden-onset infectious diseases are their suddenness and lack of effective treatment. As the epidemic develops and different variants appeared, research on the evolution of the epidemic and the effectiveness of containment and mitigation strategies is systematic. This study identifies the key prevention and control factors affecting the severity of the epidemic in Italy. We analyze specifically the effect of non-pharmaceutical interventions and vaccination.

Model

Since the epidemic is complex, We have decided to use the SIDARTHE-V compartmental model. This model is introduced by Giordano et al., extends the SIDARTHE model by including the effect of vaccination. It captures the daily dynamic interactions among nine mutually exclusive infection states of the population in Italy.

$$\dot{S}(t) = -S(t)(\alpha I(t) + \beta D(t) + \gamma A(t) + \delta R(t)) - \varphi(S(t)) \quad (1)$$

$$\dot{I}(t) = S(t)(\alpha I(t) + \beta D(t) + \gamma A(t) + \delta R(t)) - (\varepsilon + \zeta + \lambda)I(t) \quad (2)$$

$$\dot{D}(t) = \varepsilon I(t) - (\eta + \rho)D(t) \quad (3)$$

$$\dot{A}(t) = \zeta I(t) - (\theta + \mu + \kappa)A(t) \quad (4)$$

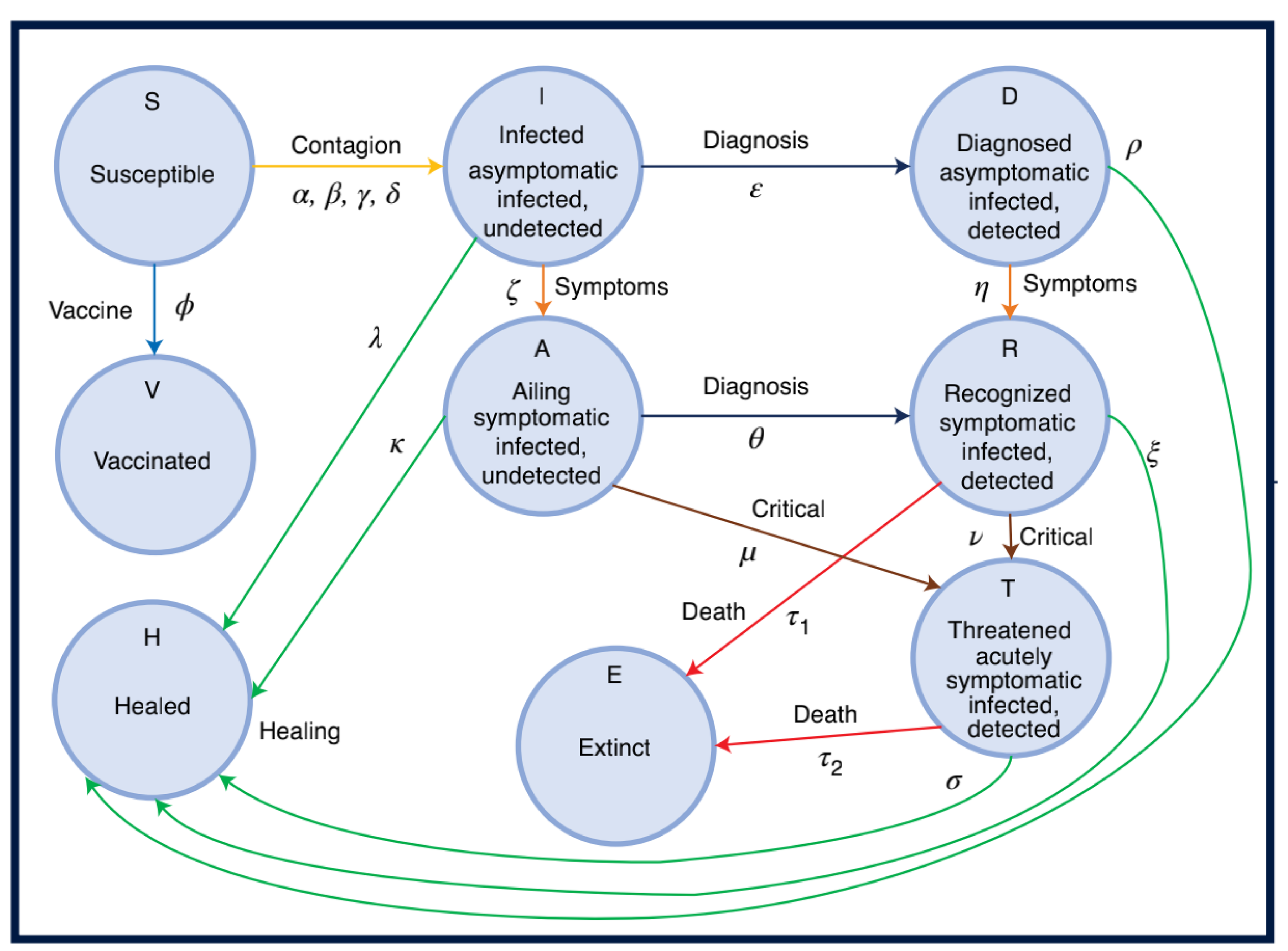
$$\dot{R}(t) = \eta D(t) + \theta A(t) - (\nu + \xi + \tau_1)R(t) \quad (5)$$

$$\dot{T}(t) = \mu A(t) + \nu R(t) - (\sigma + \tau_2)T(t) \quad (6)$$

$$\dot{H}(t) = \lambda I(t) + \rho D(t) + \kappa A(t) + \xi R(t) + \sigma T(t) \quad (7)$$

$$\dot{E}(t) = \tau_1 R(t) + \tau_2 T(t) \quad (8)$$

$$\dot{V}(t) = \varphi(S(t)) \quad (9)$$



Interpretation

By comparing the predicted active cases with and without vaccination in Fig.2, we observe that the vaccination can bring improvements, and what affects significantly the evolution is the reproduction number $\mathcal{R}_0$, *i.e.* a low $\mathcal{R}_0$, the number of active cases won't increase significantly.

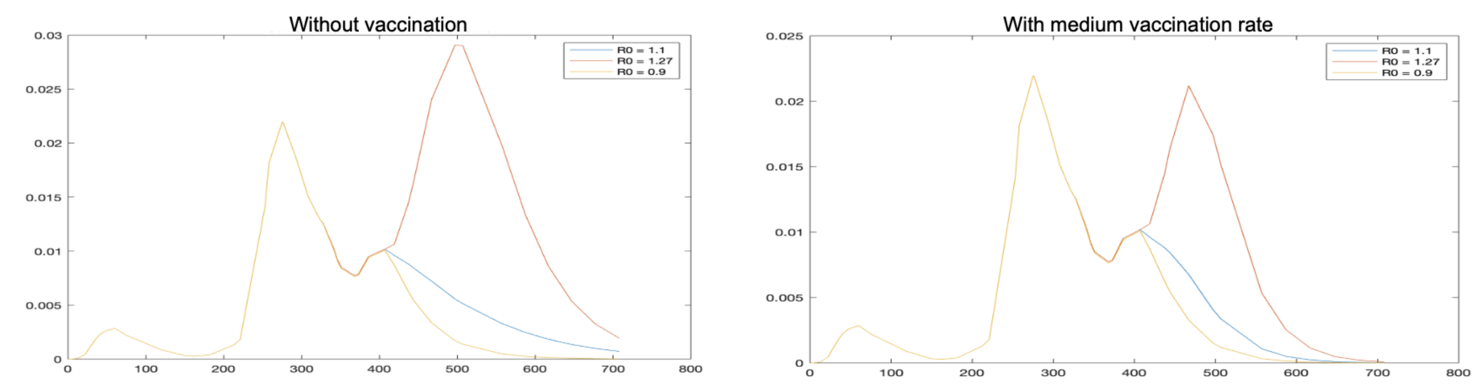


Fig. 2: Comparison of predicted active cases between no vaccination and with medium vaccination rate

$\mathcal{R}_0$ is time-varying, it depends on the adopted containment measures, the effectiveness of therapies, and the efficacy of testing and contact tracing. However, with the same average value of $\mathcal{R}_0$ equal to 1.1, we observe that the Close-Open intermittent strategy has an evolution slightly better than with Open-close.

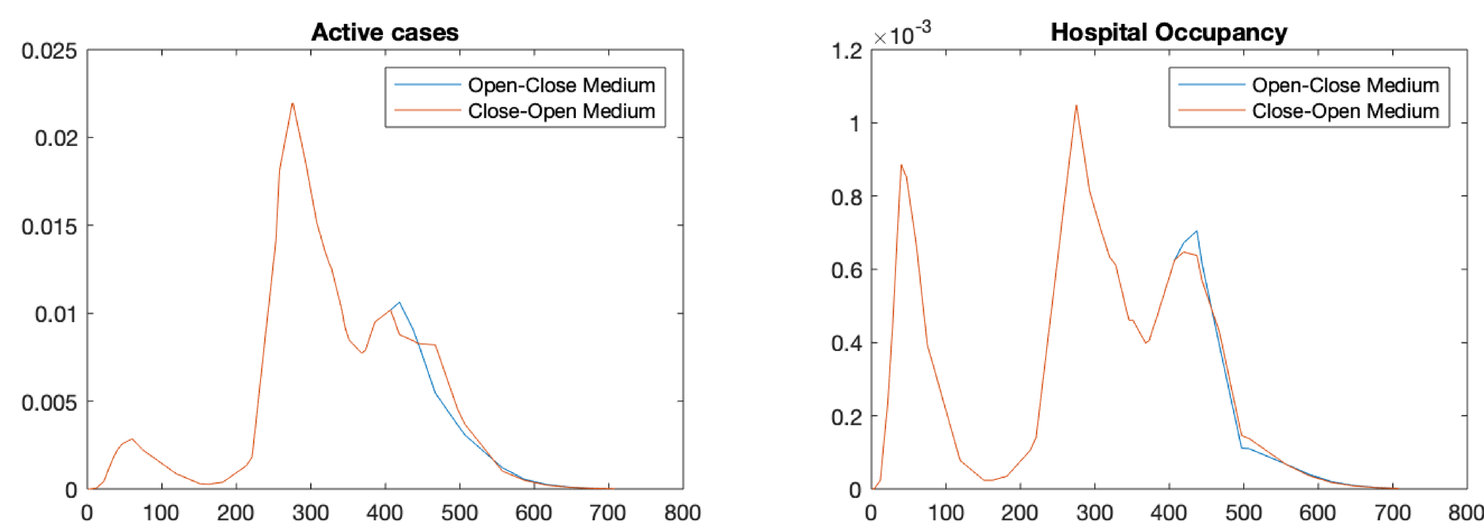


Fig. 3: Comparison between Open-close and Close-open strategy with medium vaccination rate

We have 18 parameters in our model, by analyzing the sensitivity of hospital occupancy, by adding 10% to each parameter, we observe three parameters affect significantly our model among others:

- α : the principle contagion parameter affects positively hospital occupancy.
- ε : the principle diagnosis parameter affects negatively hospital occupancy.
- λ : the principle healing parameter affects negatively hospital occupancy.

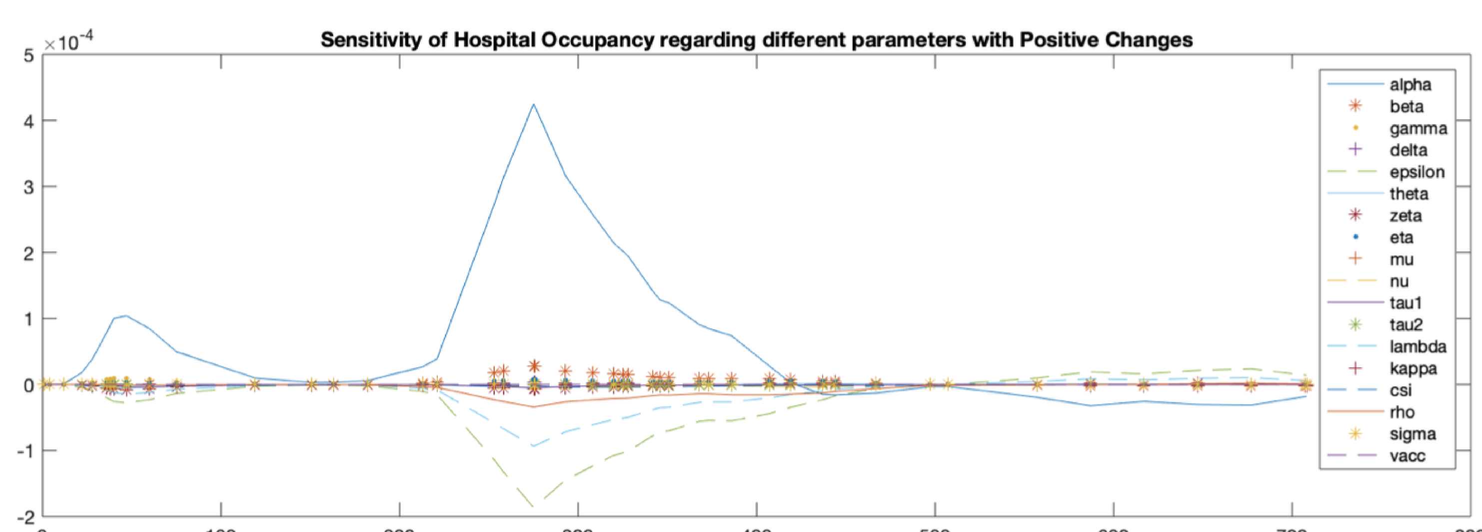


Fig. 4: Sensitivity of Hospital occupancy regarding different parameters with 10% positive changes

Result

By adapting the parameters, our model predicts the evolution from late February 2020 to March 2022. Our approximation is very similar to the reality (with data to Mid-November 2021). And due to the new variant Omicron, which has a high contagion rate, and people will travel during the Christmas holiday, our model thinks the number of active cases will keep increasing and will attend a peak in January.

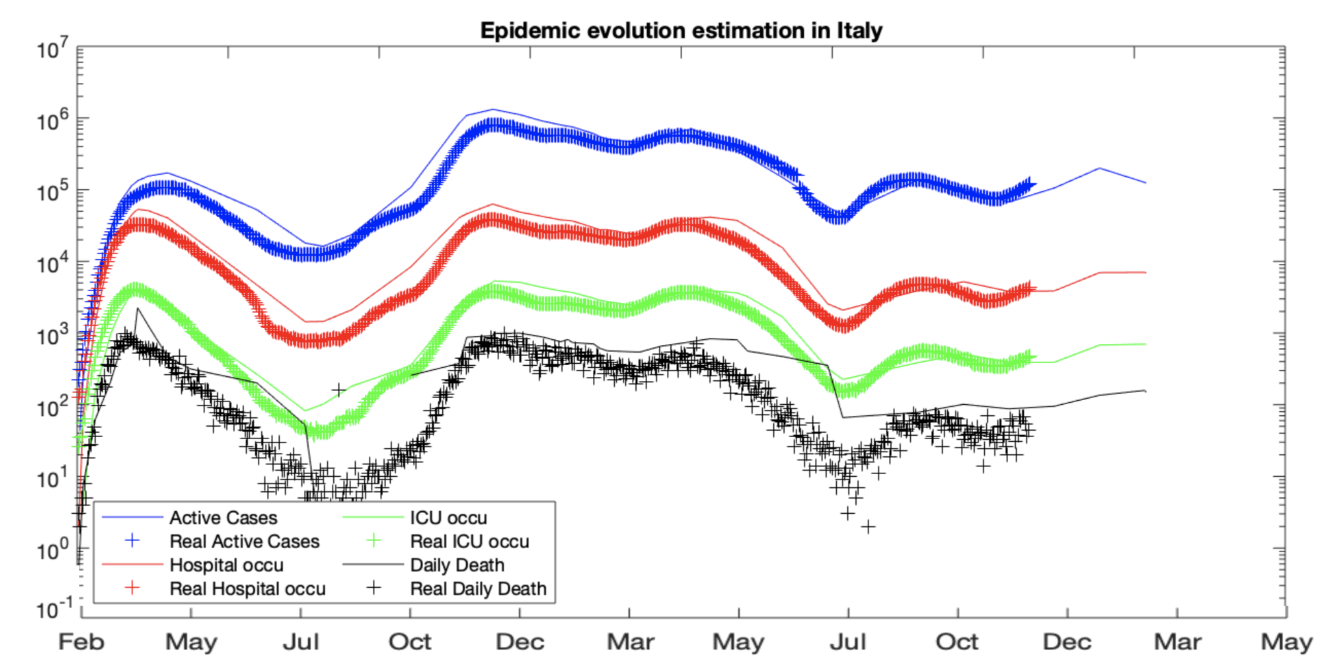


Fig. 5: Epidemic evolution in Italy from late February 2020 to March 2022.

Conclusion

Among the three important parameters identified, what we can make effort is the contagion parameter. The vaccination can affect the spread of viruses, but given the occurrence of different variants and the uncertainty of the current vaccine against those variants, we can essentially reduce the contagion parameter by introducing non-pharmaceutical intervention (NPI)
Most NPI can hurt the general well-being of people and affects negatively the functioning of society and the economy. Therefore, by adapting the parameter of the model, we can determine which level of NPI is necessary, to avoid non-necessary actions.

Remarks

Our model depends strongly on those 19 parameters, if we want to apply this model to another country, we need further study on this country to use the correct parameters. Furthermore, we didn't introduce the diminution of effectiveness of the vaccine, for example, currently, vaccinated people should take their 3rd dosage to keep the vaccine active in their body.

References

[1] *Epidemiological data on the evolution of the COVID-19 epidemic in Italy.* `https://github.com/pcm-dpc/COVID-19/tree/master/dati-andamento-nazionale`.

[2] G. Giordano et al. "Modeling vaccination rollouts, SARS-CoV-2 variants and the requirement for non-pharmaceutical interventions in Italy". In: *Nature Medecine* 27 (June 2021), pp. 993–998.

[3] HAIRER et al. *Solving Ordinary Differential Equations I. Nonstiff Problems.* Springer, 1993, p. 528.