Multi-stage Modeling of COVID-19 Pandemic

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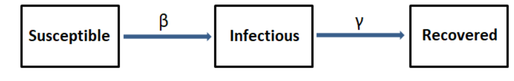
Abstract

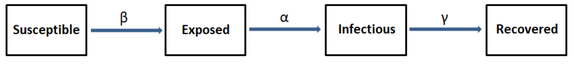
- Modeling the COVID-19 pandemic in a multi-stage manner to evaluate the effectiveness of policies taken by Italy, United Kingdom, Turkey, United States.
- Providing guidance for future policy making process.
- Finding specific time points at which the transmission rate changes sharply by Unscented Kalman Filter.
- Utilizing the time points as splitting points for multi-stage SIR and SEIR modeling.
- Evaluating results by R^2 score.
- Comparing the splitting points with actual time points of policies to reflect the effectiveness of policies.

Methods

- **Research Problem**: Model the COIVD-19 pandemic and evaluate the effectiveness of policies.
- **Approach Overview**:
  1. **Data Source**: `https://ourworldindata.org/coronavirus-source-data`.
  2. **Finding the splitting time points by Unscented Kalman Filter[2]**: UKF utilizes daily new cases as a measurement to estimate the state functions, which are compartmental models.
  3. **Tracking daily new cases by compartmental models[1]**: β: Transmission Rate; γ: Recovery Rate; α: Incubation Rate
     1. Susceptible Infectious Recovered Model



     2. Susceptible Exposed Infectious Recovered Model



  4. **Solving compartmental models**: Solving the ODES and optimizing parameters by non-linear least square fit.
  5. **Evaluating Models**: R^2 score.

Unscented Kalman Filter Results

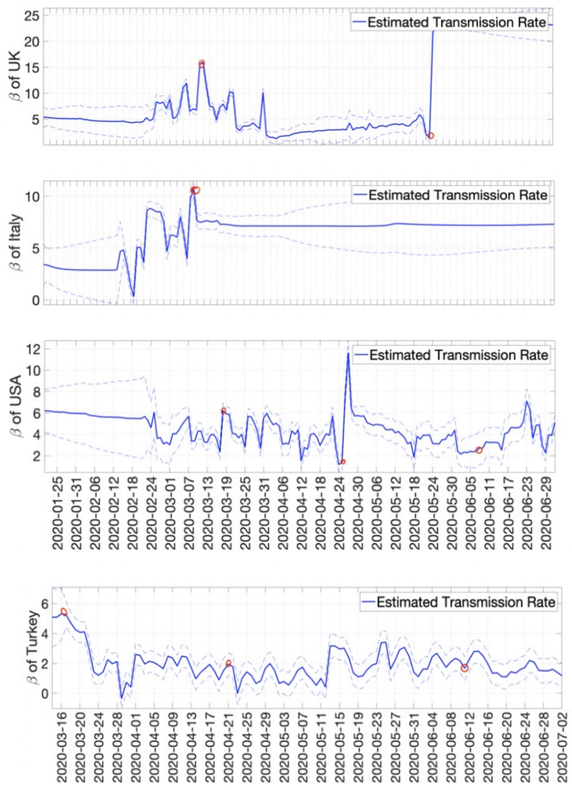


Figure 1:Transmission Rate of UK, Italy, USA, and Turkey.

- X-axis values corresponds to the red dots are the time points when the transmission rate β changes sharply. These points are chosen by our speculation.

Multi-stage SEIR, SIR and UKF Fitting

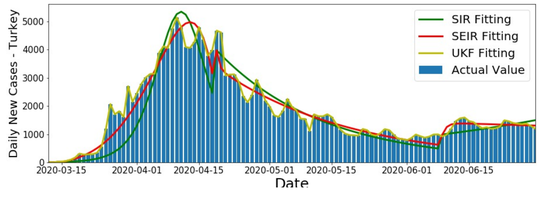


Figure 2:Multi-stage SEIR, SIR and UKF Fitting.

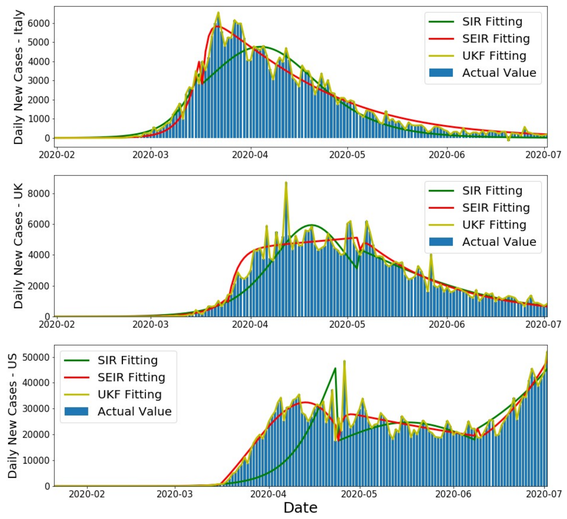


Figure 3:Multi-stage SEIR, SIR and UKF Fitting.

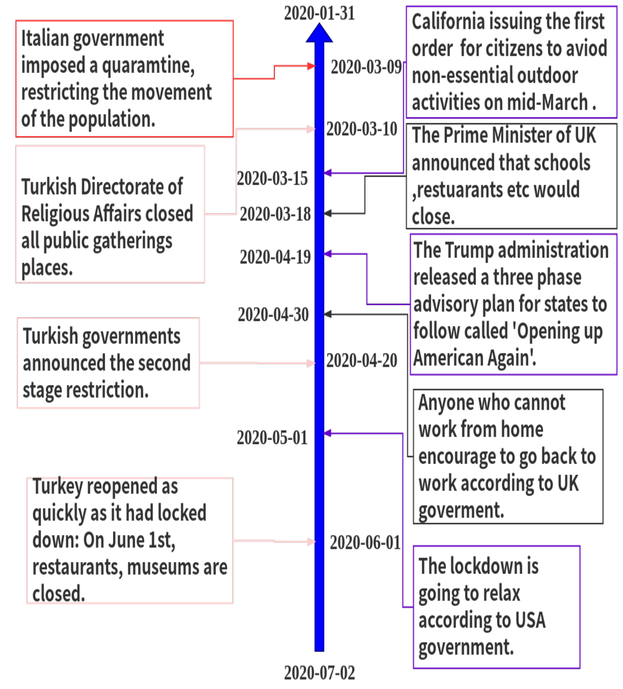
Overall Performance

Cn	Ss SIR	Ss SEIR	Ms SIR	Ms SEIR	UKF
USA	-0.208	-0.381	0.778	0.924	0.999
			-0.619	0.895	
			0.566	0.171	
			0.819	0.889	
			0.687	0.947	
Italy	-0.724	-0.183	0.953	0.886	0.999
			0.862	0.950	
			0.989	0.952	
UK	0.649	0.145	0.878	0.915	0.999
			0.079	0.503	
			0.855	0.887	
			0.860	0.919	
Turkey	-1.661	-1.359	0.941	1.000	0.999
			0.754	0.927	
			0.837	0.881	
			-0.839	0.413	

Ss: Single stage; Ms: Mulsti-stage; Score in black: individual stage; Score in red: All stages.

Policy Timeline and Discussion

- Time points of UKF do not match the actual dates of policies.Transition rate usually changes sharply several days later than the announce date of policies. Decision makers should be aware of this phenomenon and shorten the delay when developing policies.



Conclusion

- With the help of Unscented Kalman Filter, we find the time points where transmission rate (β) changes sharply.
- By splitting the data into multiple stages according to the time points indicated by UKF, the models have good fitting results, especially in the case of SEIR.
- Comparing with the actual time of different policies, the time points indicated by UKF suggest that there will be some delay for policies to take into effect.

References

[1] *Compartmental models*. URL: `https://en.wikipedia.org/w/index.php?title=Compartmental_models_in_epidemiology&oldid=966878040`.

[2] Eric A Wan and Rudolph Van Der Merwe. "UKF". In: *Proceedings of the IEEE 2000 Adaptive Systems for Signal Processing, Communications, and Control Symposium (Cat. No. 00EX373)*. Ieee. 2000, pp. 153–158.