Supplementary Material

# Settings

Iran is the second largest country in the Middle East with a population of more than 80 million people. Iran is divided into 31 provinces. Tehran is the capital and the economic center of Iran with a population of nearly 9 million in the city and more than 16 million in the larger metropolitan area. More than 70% of Iran’s population live in urban areas. For more information about Iran and the status of its health system, readers are referred to [1].

A picture containing text, map

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**Figure S1. Map of Iran showing province names.**

# Mathematical Epidemic Model

We describe the dynamics of spread using a variation of the susceptible-exposed-infected-recovered-dead (SEIRD) model, where (considering COVID-19 properties) we define the exposed group as the individuals that are infectious yet asymptomatic, so cannot be practically counted in reported infected cases. The model allows for a distributed delay in the onset of symptoms in cases after contracting the virus and a distributed delay in recovery (approximately equal for death [3]) after the onset of symptoms, and can be explained with the below system of differential equations.

|  |  |
| --- | --- |
|  | (1) |
|  | (2) |
|  | (3) |
|  | (4) |
|  | (5) |
|  | (6) |
|  | (7) |

where denotes the total population, which at each time is divided into classes of susceptible , exposed , infected , recovered , and dead cases. is the probability distribution function of a Gamma distribution over time with mean and standard deviation , for which we have . Furthermore, represents the disease transmission rate or transmissibility, recovery rate of the infectious disease can be calculated as , and represents the fatality rate defined as the proportion of deaths in the combined removed and recovered population. To account for underreporting, we also introduce a new parameter representing the percentage of symptomatic cases reported following a lognormal distribution [4]. Accordingly, and represent the fraction of infected and recovered cases reported. If underreporting exists, and and .

Table S1 provides a summary of the delay distributions considered in the model. Accordingly, parameters of the delay distributions are set as , , , .

**Table S1. Summary of major modelling assumptions and input variables**

|  |  |  |  |
| --- | --- | --- | --- |
| **Model Input** | **Distribution** | **Parameters** | **Reference** |
| Incubation period (exposure-to-onset delay) used in the SEIR model | Gamma | Average of 5.5 days and a standard deviation of 2.29 days | [2] |
| Onset-to-recovery delay used in the SEIR model | Gamma | Average of 22.2 days and a standard deviation of 10 days | [3] |
| Onset-to-death delay used in the SEIR model which approximately same as the Onset-to-recovery delay | Gamma | Average of 22.3 days and a standard deviation of 9.4 days | [3] |
| Hospitalization-to-death delay  used in estimation of under-reporting | Log-normal | Average of 13 days and a standard deviation of 12.7 days | [4] |
| Under-reporting (percentage of symptomatic COVID-19 cases reported) | Log-normal | Average of 9.9% and a standard deviation of 4% | [4] |

To estimate the underreporting percentage, the base CFR is assumed 1.4%. Based on the method presented in [4], the under-reporting can be estimated as 1.4%/cCFR where cCFR represents corrected CFR based on the delay distribution from hospitalization-to-death. Note that cCFR is different that the delay-adjusted CFRs shown in the Figure 1 in the manuscript. We obtained the cCFR for Iran from [4] at the time of analysis (mean cCFR=14.14%). If a country has a cCFR that is higher, it suggests that only a fraction of cases have been reported (in this case, 1.4/14.14 = 9.9% cases reported approximately). The calculated cCFR follows a log normal distribution. Therefore, 1.4/cCFR can also be approximated by a lognormal distribution.

When estimating the effective reproduction number, different time window lengths could be used. Here we conduct a comparative analysis to understand the impact of the rolling time window length on the estimated effective reproduction number. Figure S2 shows the estimated the effective reproduction number using 7-day and 14-day rolling time windows. Selection of the appropriate time window length generally depends on the expected pattern fluctuations in the observed data. We believe a 14-day window is too large and thus, makes the estimation less sensitive to changes in the patterns in the data. Any time window smaller than 7-day may also be too short to result in reliable model parameter estimation outcomes.

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**Figure S2. Impact of rolling time window length on the effective reproduction number**

# Model Limitations

The model does not take into account the imported cases. The model does not capture the impact of quarantine and self-isolation of confirmed cases. While the model produces stochastic outcomes due to various delay distributions used as input, the model parameters are deterministic. The model does not take into account the population age distribution. It is also assumed that underreporting remains unchanged over time.

# References

1. Danaei G. et al. Iran in transition. The Lancet. (2019) 392 (10184): 1984-2005. doi:10.1016/S0140-6736(18)33197-0.
2. Lauer SA, Grantz KH, Bi Q, et al. The Incubation Period of Coronavirus Disease 2019 (COVID-19) From Publicly Reported Confirmed Cases: Estimation and Application. Ann Intern Med. (2020) [Epub ahead of print 10 March 2020]. doi:10.7326/M20-0504.
3. Imperial College London COVID-19 Response Team. Report 4: Severity of 2019-novel coronavirus (nCoV). February 10, 2020. https://www.imperial.ac.uk/media/imperial-college/medicine/sph/ide/gida-fellowships/Imperial-College-COVID19-severity-10-02-2020.pdf (accessed April 13, 2020).
4. CMMID. Using a delay-adjusted case fatality ratio to estimate under-reporting. April 4, 2020. Centre for Mathematical Modelling of Infectious Disease, London School of Hygiene & Tropical Medicine. <https://cmmid.github.io/topics/covid19/global_cfr_estimates.html> (accessed April 13, 2020).